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Radiation-Neutralization of Stored Biological Warfare Agents with Low-Yield Nuclear Warheads

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Abstract

MCNP Monte Carlo radiation transport computations were performed exploring the capability of low-yield nuclear fusion and fission warheads to neutralize biological warfare agents with the radiation dose deposited in the agent by the prompt neutron output. The calculations were done for various typical storage configurations on the ground in the open air or in a warehouse building.

This application of nuclear weapons is motivated by the observation that, for some military scenarios, the nuclear collateral effects area is much smaller than the area covered with unacceptable concentrations of biological agent dispersed by the use of conventional high explosive warheads.

These calculations show that biological agents can be radiation-neutralized by low-yield nuclear warheads over areas that are sufficiently large to be useful for military strikes. This report provides the calculated doses within the stored agent for various ground ranges and heights-of-burst.

Introduction

Storage tanks containing biological warfare agents that are located in buildings or open areas are relatively easy to damage with conventional high explosive warheads. However, this is likely to cause dispersal of the agents. Under some conditions this dispersal can cover very large areas with unacceptable concentrations of biological agent. These biological hazard areas can be very much larger than the collateral damage areas due to the various prompt effects and the radioactive fallout produced by a low-yield nuclear explosion. For this reason, the use of nuclear weapons for neutralization of stored biological warfare agents is sometimes considered.

Nuclear explosions produce many effects that can potentially destroy a biological agent. These effects include blast overpressure, prompt radiation dose, fireball heat, and radiation dose from the delayed gammas and neutrons emitted by the fission debris cloud. The extent to which fireball heat and delayed fission debris radiation will affect the agent depends on the details of how the agent-filled containers are broken open by the blast and other explosion effects, and on the details of the subsequent dispersal of the spilled agent and its mixing with the rising fireball and fission debris cloud. All this is very difficult to treat in sufficient detail with available computer codes. On the other hand, the radiation dose deposited in the agent can be accurately computed given a particular storage configuration. This makes agent neutralization by the prompt radiation output a potentially attractive kill mechanism of nuclear warheads.

It is the purpose of this report to summarize the results of our Monte Carlo computations exploring the capability of low-yield nuclear fusion or fission warheads to neutralize biological agents via the radiation dose deposited in the agent by the prompt neutron output. Since the incremental dose from the prompt gamma output can be shown to be relatively small, it has not been included in these Monte Carlo computations.

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Biological agent is typically stored in barrels or larger storage containers. Aggregates of such barrels or containers can be arranged in a variety of storage configurations. Our Monte Carlo calculations treated several configurations which we believe to be representative of typical storage practices.

We used the MCNP coupled neutron-photon Monte Carlo code for our radiation transport computations [1].

Nuclear Warhead Neutron Outputs

For the nuclear warhead, we used the same generic fission and fusion types described in our previous reports [2,3].

Our neutron spectra and total neutron emissions per unit of yield are those described by Loewe [4] in the open literature:

Fission type – Army Pulsed Radiation Facility (APRF) reactor leakage spectrum and 0.4 mols of neutrons per kiloton.

Fusion type – Mono-energetic 14 Mev neutrons from the deuterium-tritium reaction and 2.5 mols of neutrons per kiloton.

For the APRF spectrum, we used calculations performed by Kaul et al [5], which we plot in Fig.1.

Radiation Neutralization Criterion

The current U.S. standard for commercial radiation sterilization of medical products to be used inside the human body is a minimum dose of 2.5 Megarad [6]. Such sterilization is usually done with electron beams or gamma sources.

The total dose in the agent in our calculations consists of energy deposited by neutron interactions and energy deposited by neutron-induced gamma interactions. It will be shown in the remainder of this report, that for the typical agent storage configurations examined here, the total radiation dose in the agent on top of the barrel or container stack is dominated by the neutron dose for the fusion warhead. For the fission warhead, neutrons and gammas contribute approximately equally to the total dose at the top of the stack. For agent located at the bottom of the stack, most of the dose is due to gammas for both warhead type.

A given dose produced by neutrons is known to be much more damaging to biological systems than the same dose due to gamma or electron interactions, based e.g. on the incidence of cancer among survivors of the Hiroshima and Nagasaki nuclear explosions. However, there appear to be no data published in the open literature addressing the relative effectiveness of neutrons and gammas for neutralization of biological warfare agents.

The author of this paper has used, in his past reports, a radiation neutralization criterion of one Megarad for biological agent such as anthrax [2, 3]. Until neutron and gamma exposure data for various potential biological warfare agents become available, a total combined neutron and gamma dose of 1 Megarad continues to be a useful zero-order criterion for assessing the agent neutralization capability of nuclear warheads. This criterion will be used in this report.

MCNP Monte Carlo Code Problem Geometries

Five different problem geometries were set up for the MCNP computations:

1. A 500 meter radius, 2 meter thick layer consisting of a homogeneous mixture of agent and steel barrels, located on the ground in open air (Fig. 2). This layer represents a large area covered by densely stacked agent-filled barrels.
2. A pyramid stack of ten 200-liter steel barrels filled with agent, on the ground in open air or in a concrete block building with a concrete roof (Fig. 20).
3. A single-layer running stack of six one-ton steel containers filled with agent, on the ground in open air or in a concrete block building with a concrete roof (Fig. 25 with the upper layer of containers removed).
4. A double-layer running stack of eleven one-ton steel containers filled with agent, on the ground in open air or in a concrete block building with a concrete roof (Fig. 25).
5. A cylindrical concrete block building with a steel roof, with a radius varying between 15 and 85 meters, densely packed with double-layer running stacks of 200-liter agent-filled steel barrels to within 3.5 meters from the concrete block wall (Fig. 30).

For all geometries, the soil was 5 meters thick with a radius of 4 km for the first geometry and 1km for the other four geometries. The composition of the soil was dense mixed-grain sand (SiO_2) with 16 weight percent water and its density was 2.16 g/cc. On top of the soil was a sealevel-density hemisphere of air with a radius equal to that of the soil. The composition used for the concrete block walls and the concrete roof was that of ordinary Portland-cement based concrete [7]. The density of the concrete block was 1.2 g/cc and that of the light-weight concrete roof was 1.5 g/cc. The agent was modeled as water with a density of 1.0 g/cc. The agent/barrel mixture used in the first geometry modeled densely stacked 330-liter agent-filled barrels. This mixture had a density of 0.993 g/cc with 16.6 percent of the mixture mass consisting of iron. The agent/barrel mixture used at the center of the fifth geometry modeled densely stacked 200-liter agent-filled barrels. The density of this mixture was 1.02 g/cc and it contained 13.8 weight percent iron.

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For the pyramid barrel stack and the one- and two-layer running container stacks, i.e. the second, third, and fourth problem geometries, the stack consisted of cylindrical barrels and containers when the burst point was directly above the stack (zero ground range). When the burst point was offset from the stack by a finite ground range, the stack consisted of toroidal barrels or containers centered on ground zero. This shape was chosen in order to increase the probability of neutrons interacting with the agent and thus improving the Monte Carlo statistics of the computed agent radiation dose. This toroidal configuration is shown in the figures.

The outside dimensions of our 200-liter barrel are 50 cm diameter and 100 cm height; those of our one-ton container are 80 cm diameter and 200 cm height. These barrel and container volumes are nominal values.

For the zero-ground-range cases, the cylindrical barrels had a 300 cm axial dimension, representing three closely spaced 200-liter barrel stacks lying on the ground with their end surfaces touching. The agent zones, in which the energy deposition was tallied, were 50 cm long. They were centered on the midpoint of the barrel. The cylindrical containers had a 200 cm axial dimension with 100 cm long tally zones centered on the container midpoint.

The toroidal stacks thus actually represent a closely spaced linear array of stacks of cylindrical barrels or containers. The adjacent stacks provide some shielding at the ends of the cylinders. Thus the radiation dose inside an isolated single stack of barrels or containers will be somewhat higher than computed here with the toroidal shapes.

Computed Radiation Doses

The computed total radiation doses due to neutron and neutron-induced gamma interactions will now be summarized and discussed for each of the five geometries. The summaries for the barrel and container stacks will only deal with the lowest dose found in the stacks. In most geometries, this lowest dose is found in the bottom zone, i.e. the zone in contact with the ground, in that barrel that is just downrange from the vertical centerline of the stack. This is the zone of interest if the purpose of the explosion is to raise the dose in all the agent within the stack above some neutralization criterion.

The radiation doses for all the stack zones for all MCNP computations reported here are tabulated in the Appendix. All radiation doses are normalized to a ten kiloton yield. They can be linearly scaled to other yields of interest.

The total number of source neutrons used in each MCNP computation ranged between about 5 million to about 20 million. In most computational runs this number was sufficient to reduce the statistical uncertainty in the zone with the lowest dose to less than ten percent. The statistical uncertainty for each of the bottom zones is shown in the tabulations contained in the Appendix. The statistical uncertainty for the other zones in the stack is smaller by a factor that is roughly inversely proportional to the square root of the total dose.

1.Homogeneous agent/barrel mixture layer

In Fig. 3 the radiation dose due a 10 kT burst is plotted versus height-of-burst (HOB) for agent zones that had an average depth from the layer's surface ranging from 10 to 190 cm and an average ground range of 2.5 m. These are the cylindrical zones directly under the burst point. Figs. 4 – 10 are similar plots for annular zones at ground ranges from 10 to 450 m. Figs. 11 – 18 show such plots for a 10 kT fusion burst.

It can be seen from these figures that there is a particular HOB that maximizes the radiation dose in agent that is located at a given ground range from the burst point. A HOB that is lower or higher than this optimum HOB will result in a lower dose. For example, for a fission warhead the optimum HOB is about 10 m for a ground range of 10 m, and about 50 m for a ground range of 70 m. For a fusion warhead, the optimum HOB is similar. This information is useful for selecting a HOB that will maximize the area over which an area-like agent target, such as a storage yard filled with agent containing barrels, will receive a neutralizing dose.

These figures are also useful for making zero-order estimates of dose deposited at the bottom of a barrel stack of some effective average height at some ground range. Based on such a use of these figures, the HOB was chosen as 10 m for most of the following MCNP computations involving more detailed agent storage configurations. However, some additional MCNP calculations exploring sensitivity to HOB were also done for some of these configurations.

The neutron-to-total-dose ratio versus agent depth is shown in Fig. 19 for a subset of the computations plotted in Figs. 3 – 18 (10 m average ground range; 10 m HOB). It can be seen that neutron interactions account for a large fraction of the dose in the zone near the surface for both the fission and fusion warhead. The fractional neutron dose from the fission warhead falls off much more rapidly with depth than that from the fusion warhead.

2. Pyramid stack of 200-liter barrels

The lowest radiation dose in the pyramid barrel stack versus ground range is plotted in Fig. 21 for both 10 kT fission and fusion yields at 10 m HOB. This figure shows the dose for the stack both in the open air and in a concrete block building. It can be seen that the concrete building has little effect on the zone with the lowest dose on the bottom of the stack. Examination of the detailed dose distribution tables for the entire stack, contained in the Appendix, shows that the dose at the top of the stack is lowered by about a factor of two by the presence of the building. However, it is the lowest dose at the bottom of the stack that really matters when the purpose of the explosion is to neutralize all the agent in the stack.

For a 10 kT explosion at 10 m HOB, it follows from Fig. 21 that our radiation neutralization criterion of 1 Megarad total dose is met or exceeded in all parts of the pyramid barrel stack for the fusion weapon at ground ranges less than about 70 m and for the fission weapon at ranges less than about 10 m.

Fig. 22 shows the fractional neutron dose versus ground range for this pyramid stack for a 10 m burst height. This neutron dose is plotted for two tally zones within the stack: the upper zone of the top barrel and the bottom zone of that barrel on the ground with the lowest total dose. The fractional neutron doses for this stack are consistent with those computed for the agent/barrel mixture layer. The neutron dose fraction in the top zone of the top barrel is about 80% for the fusion and about 60% for the fission warhead. For the bottom zone of the lowest-dose barrel, the neutron fraction is about 20% for the fusion warhead and negligibly small for the fission warhead.

The HOB dependence of the lowest radiation dose at the bottom of the barrel stack is plotted in Fig. 23 for the stack in the open air or in a concrete block building. The ground ranges for this figure were chosen so that the dose for 10 m HOB was near 1 Megarad, viz. a range of 80 m for the fusion and 20 m for the fission warhead. For this isolated pyramid stack, we do not observe the optimum HOB that the calculations for the agent/barrel layer indicate. Instead, the dose stays constant over a range of burst heights near the ground and it then decreases monotonically for larger burst heights.

In order to examine the sensitivity of the dose to details of the neutron output spectrum, we performed a series of computations using mono-energetic neutron sources in the range from 20 Mev to 10 ev. Fig. 24 shows the lowest radiation dose per mol of neutrons in the pyramid stack at a 10 m ground range and a 10 m HOB, as a function of neutron energy. We note that the dose per neutron is approximately constant for neutron energies between 6 Mev and 10 ev. Thus for warheads, like our generic fission warhead, that produce neutrons in this energy range, all that matters is the total number of neutrons produced in the explosion and not the details of their energy spectrum. For neutrons with energy above 6 Mev, the dose per neutron rises significantly with increasing neutron energy – approximately proportional to the 1.5 power of the energy.

3. Single- and double-layer running stack of one-ton containers

The lowest radiation dose versus ground range in the single-layer running container stack in open air or in a concrete block building is shown in Fig. 26 for the two warhead types. Fig. 28 shows the same data for the double-layer running container stack.

These two figures show again very little effect of the building on the lowest dose in the stack. It follows from Fig. 26 that, for a 10 kT explosion at 10 m HOB, our 1 Megarad neutralization criterion is met or exceeded in all parts of the single-layer running container stack for the fusion warhead at ground ranges less than about 70 m and for the fission warhead at ranges less than about 20 m. For the double-layer running container stack, these ranges are about 15 and 5 m, respectively, as can be seen from Fig. 28.

The fractional neutron dose versus ground range for a 10 m HOB for fission and fusion warheads is shown for the single-layer running container stack in Fig. 27 and for the double-layer stack in Fig. 29. The results are similar to those observed for the pyramid stack, except that the fractional neutron dose for the bottom zone in the two-layer stack also becomes negligible for ground ranges above about 20 meters.

4. Building filled with double-layer running barrel stacks

The lowest radiation dose versus ground range in the double-layer running 200-liter barrel stacks filling the steel-roofed concrete block building is shown in Fig. 31 for the two warhead types. It can be seen that our 1 Megarad neutralization criterion is met or exceeded, for 10 kT at 10 m HOB, for the fusion warhead at ground ranges less than about 50 m and for the fission warhead at ground ranges less than about 10 m.

The fractional neutron dose versus ground range, shown in Fig. 32, is similar to that observed for the single-layer running container stack discussed above.

The dependence of the lowest radiation dose in this running stack on HOB is plotted in Fig. 33 for a ground range of 20 m. It shows an optimum HOB similar to that observed for the homogeneous agent/barrel mixture layer, i.e. about 20 m for the fusion warhead and about 10 to 20 m for the fission warhead.

Summary and Conclusions

The prompt neutron output of low-yield nuclear warheads can neutralize biological warfare agents, in typical surface storage configurations, over areas that are sufficient large to be useful for military strikes. For 10 kT, the yield used in this report, and a height-of-burst (HOB) of 10 m, a fusion warhead has a neutralization area with a radius of about 50 meters. This radius is about 10 meters for a 10 kT fission warhead. These radii are based on our one Megarad neutralization criterion.

The neutralization areas are approximately the same for agents stored on the ground in open air and for those stored in a typical one-story concrete block warehouse building.

For typical extended, densely packed storage configurations, such as running barrel stacks, there is a particular HOB that maximizes the area over which agent is neutralized. For HOB's either lower or higher than this optimum height, the neutralization area decreases. The optimum HOB depends on the ground range for which the neutralization criterion is satisfied. This, in turn, depends on the yield and warhead type. For 10 kT, the optimum HOB is approximately 40 meters for the fusion and 10 meters for the fission warhead.

The largest fraction of the dose deposited at the top of the storage stack is due to neutron interactions. The dose at the bottom of the stack is mostly deposited by gammas produced in neutron interactions in the upper region of the stack. Neutron doses are expected to be significantly more effective in neutralizing biological warfare agents than gamma doses. However, this higher neutron dose effectiveness does not enhance the neutralization area for the storage configurations used in this report since we found the lowest dose in the stack, which determines the neutralization radius, to be mostly due to gammas.

7

For neutron energies below about 6 Mev, the radiation dose deposited in the agent per neutron is approximately independent of the neutron energy. For neutrons with energy in the range from 6 to 20 Mev, the dose increases approximately in proportion to the 1.5 power of the neutron energy. This observation has two implications:

1. For warheads, such as our fission warhead, that produce neutrons with energies that are mostly below 6 Mev, it is the total number of output neutrons per unit of yield that matters, and not the details of the neutron output spectrum.
2. In order for a fission and a fusion warhead to produce the same radiation dose at the bottom of a typical storage stack, the yield of the fission warhead needs to be an order-of-magnitude larger than that of the fusion warhead.

This greater effectiveness of fusion warheads is due not only to the larger dose deposited by 14 Mev neutrons compared to that deposited by the lower-energy neutrons of fission warheads, but also due to the much larger number of neutrons per unit yield produced by fusion warheads (for our generic warhead types: 2.5 mols of neutrons per kiloton versus 0.4 mols /kT for the fission warhead).

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2. Hans Kruger and Edgar Mendelsohn, "Neutralization of Chemical/Biological Ballistic Warheads by Low-Yield Nuclear Interceptors", Lawrence Livermore National Laboratory Report UCRL-ID-110403, August 1992.
3. Hans Kruger, "Defense Against Biological or Chemical Bomblet Warheads with Nuclear Interceptors", Lawrence Livermore National Laboratory Report UCRL-ID-123815, March 1996.
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5. Dean C. Kaul and Stephen D. Egbert, "Radiation Leakage from the Army Pulsed Radiation Facility (APRF) Fast Reactor", Science Applications International Corporation Report SAIC-89/1423, May 12, 1989.
6. Yoneho Tabata et al, editors, "CRC Handbook of Radiation Chemistry", CRC Press (1991).
7. Harold Etherington, editor, "Nuclear Engineering Handbook", McGraw-Hill Pub., 1958.

Generic Fission Warhead Neutron Output Spectrum
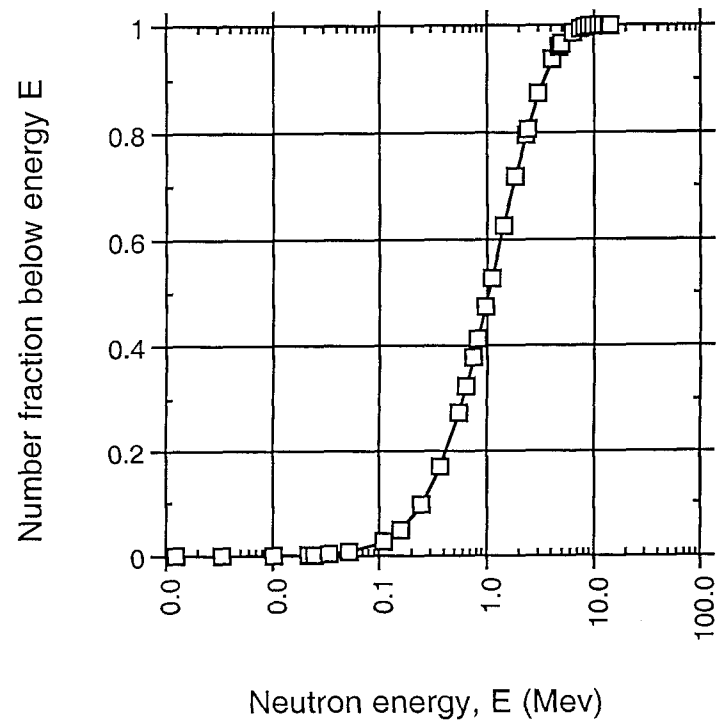
Fig. 1

MCNP Code Geometry for an Agent/Barrel Mixture on the Ground in Open Air
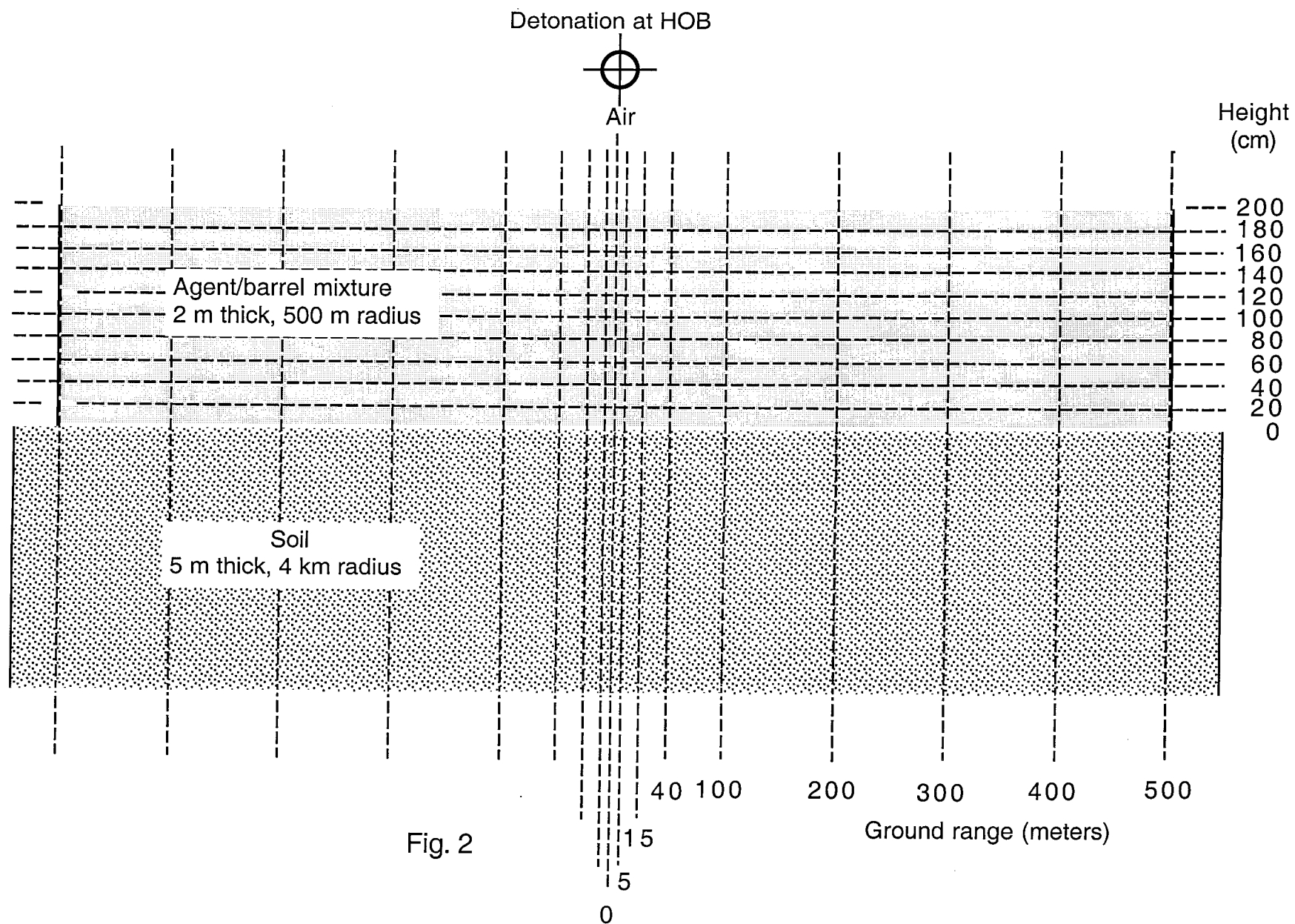
Detonation at HOB

Air

Height (cm)

Agent/barrel mixture
2 m thick, 500 m radius

Soil
5 m thick, 4 km radius

--- 200
--- 180
--- 160
--- 140
--- 120
--- 100
--- 80
--- 60
--- 40
--- 20
0

Fig. 2

40 100   200   300   400   500

15

5

0

Ground range (meters)

Radiation Dose from 10 kT Fission Yield in an Agent/Barrel Mixture on the Ground in Open Air

2.5 m ground range

10 m ground range

Agent depth (cm)

□ 10
◇ 30
○ 50
△ 70
⊞ 90
⊕ 110
⊕ 130
▽ 150
◤ 170
◆ 190

Radiation dose in agent (rad)

HOB above ground (meters)

HOB above ground (meters)
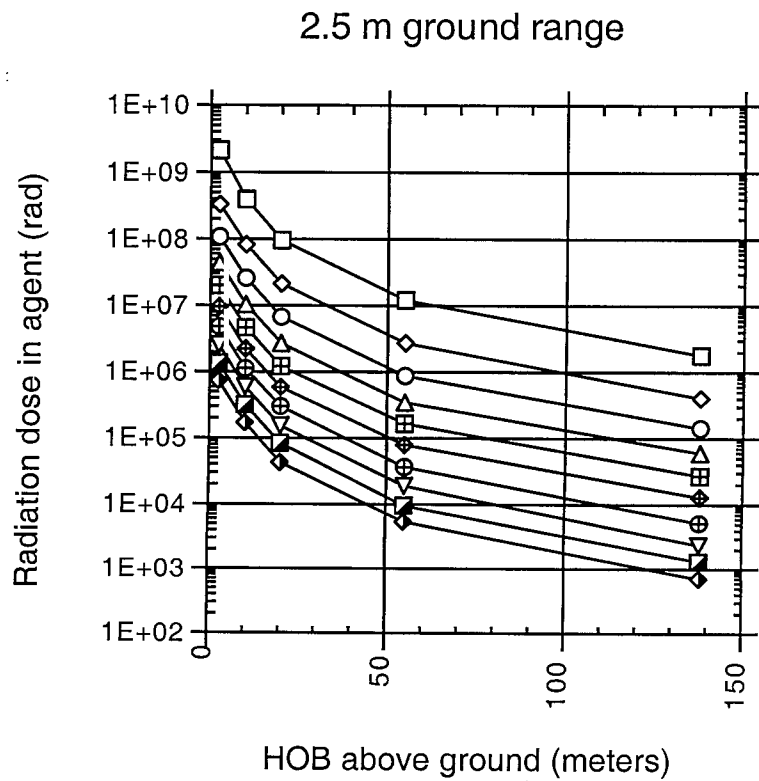
Fig. 3

Fig. 4

Radiation Dose from 10 kT Fission Yield in an Agent/Barrel Mixture on the Ground in Open Air

Fig. 5

Fig. 6

Radiation Dose from 10 kT Fission Yield in an Agent/Barrel Mixture on the Ground in Open Air

Fig. 7

Fig. 8

Radiation Dose from 10 kT Fission Yield in an Agent/Barrel Mixture on the Ground in Open Air

Fig. 9

Fig. 10

Radiation Dose from 10 kT Fusion Yield in an Agent/Barrel Mixture on the Ground in Open Air

2.5 m ground range

10 m ground range

Agent depth (cm)

□	10
◇	30
○	50
△	70
⊞	90
⬦	110
⊕	130
▽	150
◪	170
◈	190

Fig. 11

Fig. 12

Radiation Dose from 10 kT Fusion Yield in an Agent/Barrel Mixture on the Ground in Open Air

27.5 m ground range
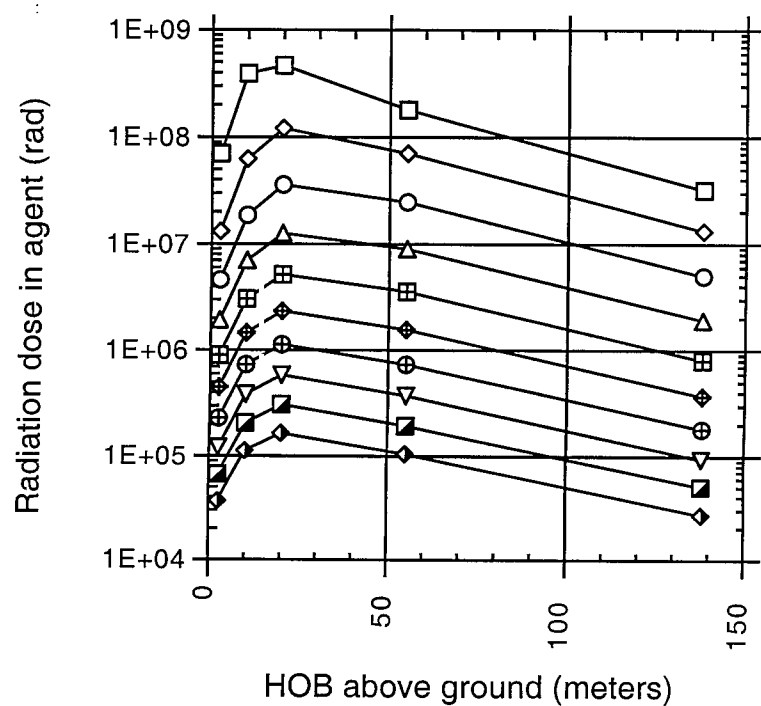
70 m ground range

Fig. 13
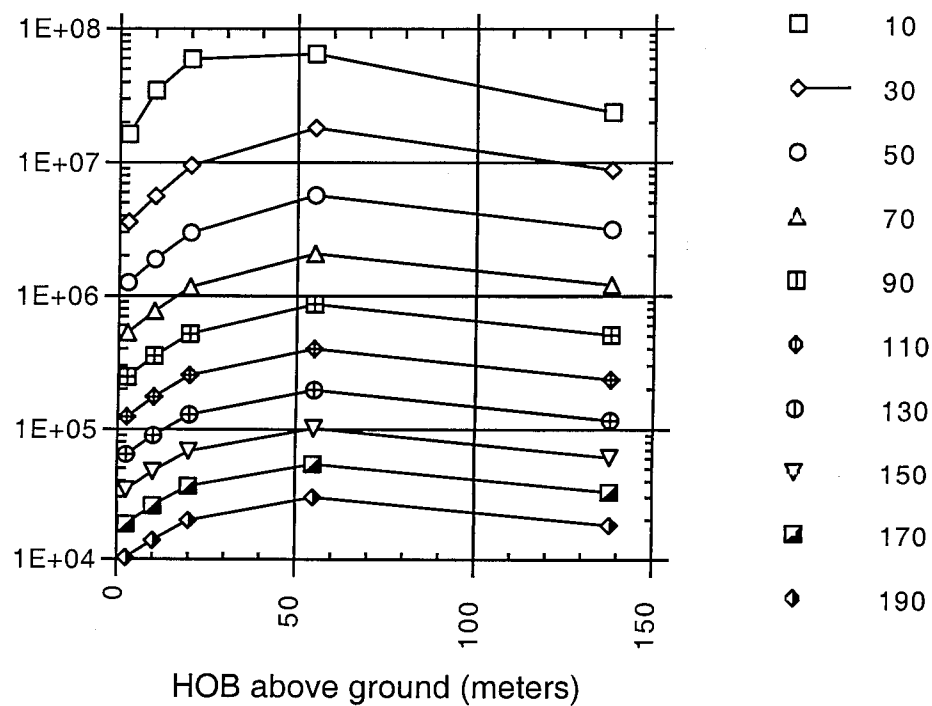
Fig. 14

Radiation Dose from 10 kT Fusion Yield in an Agent/Barrel Mixture on the Ground in Open Air
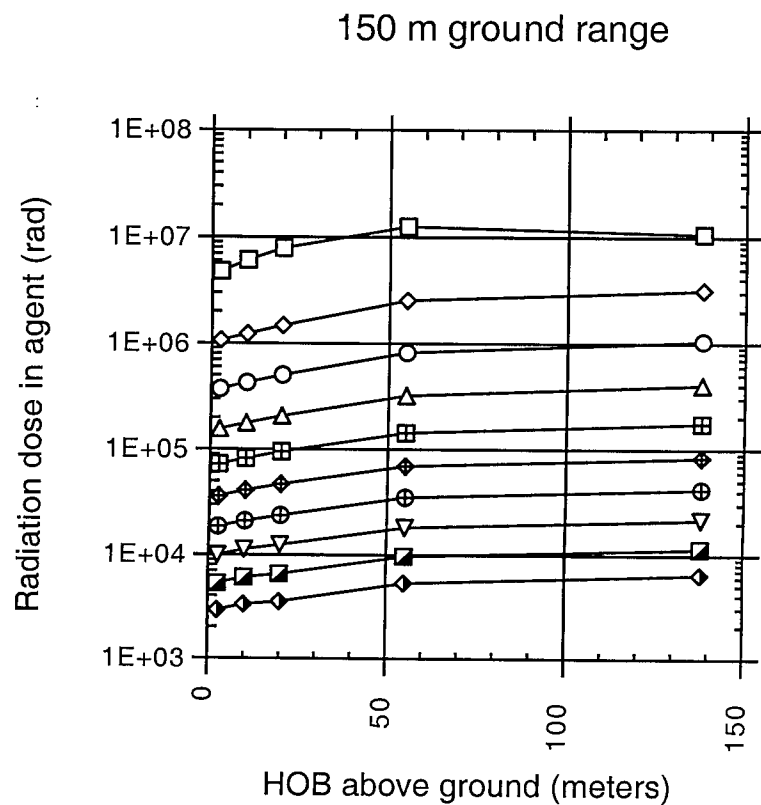
Fig. 15
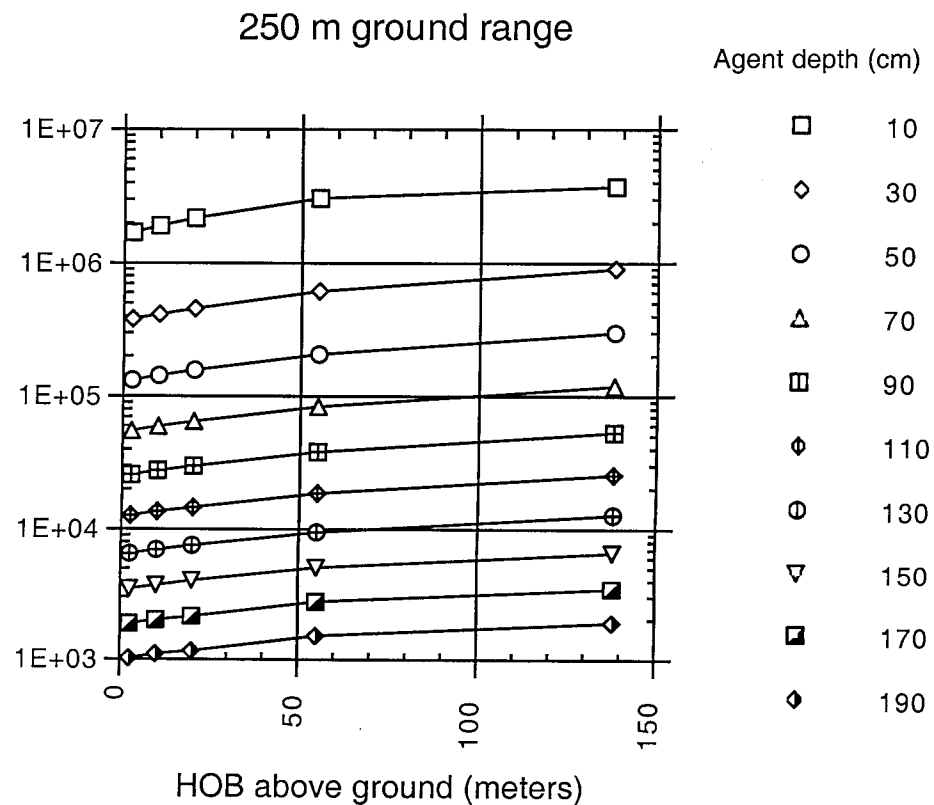
Fig. 16

Radiation Dose from 10 kT Fusion Yield in an Agent/Barrel Mixture on the Ground in Open Air
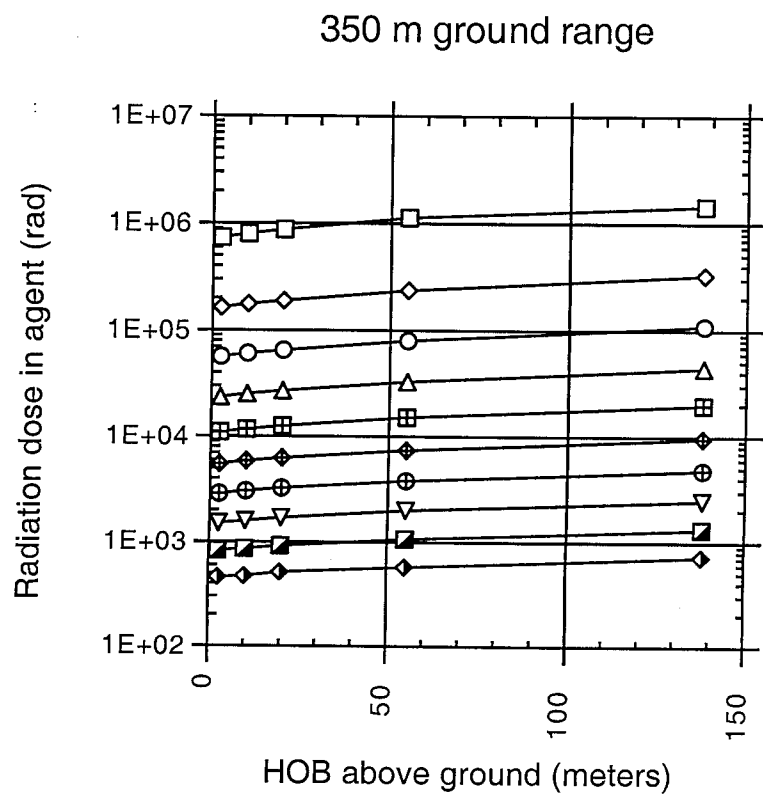
Fig. 17
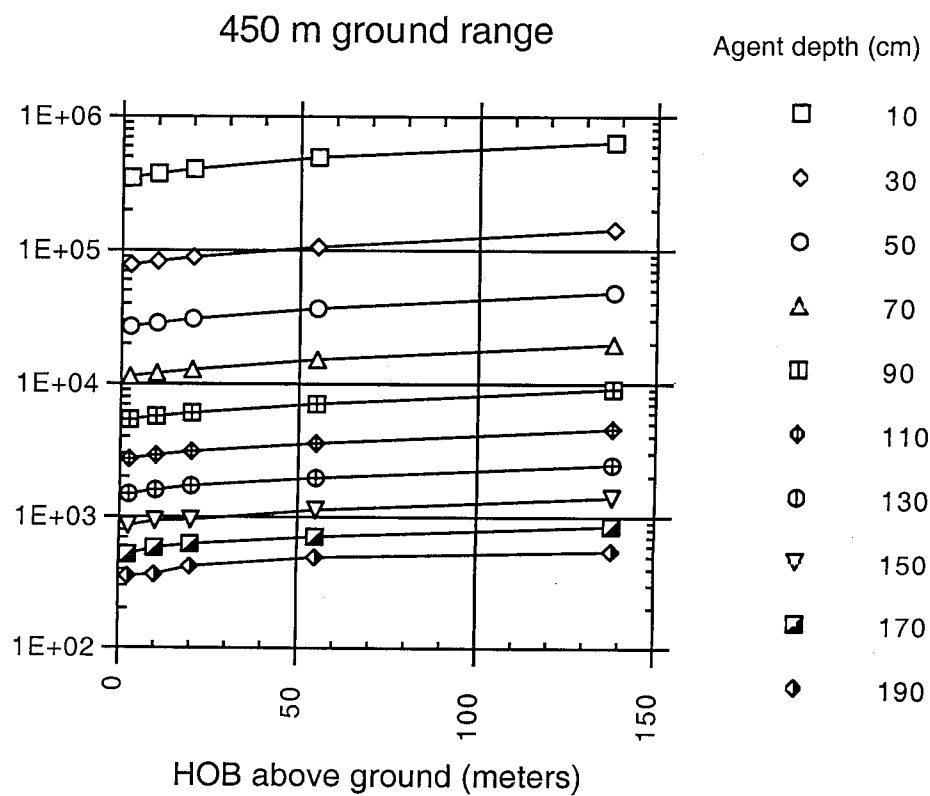
Fig. 18

Fractional Neutron Dose in an Agent/Barrel Mixture on the Ground in Open Air

10 m ground range
10 m HOB
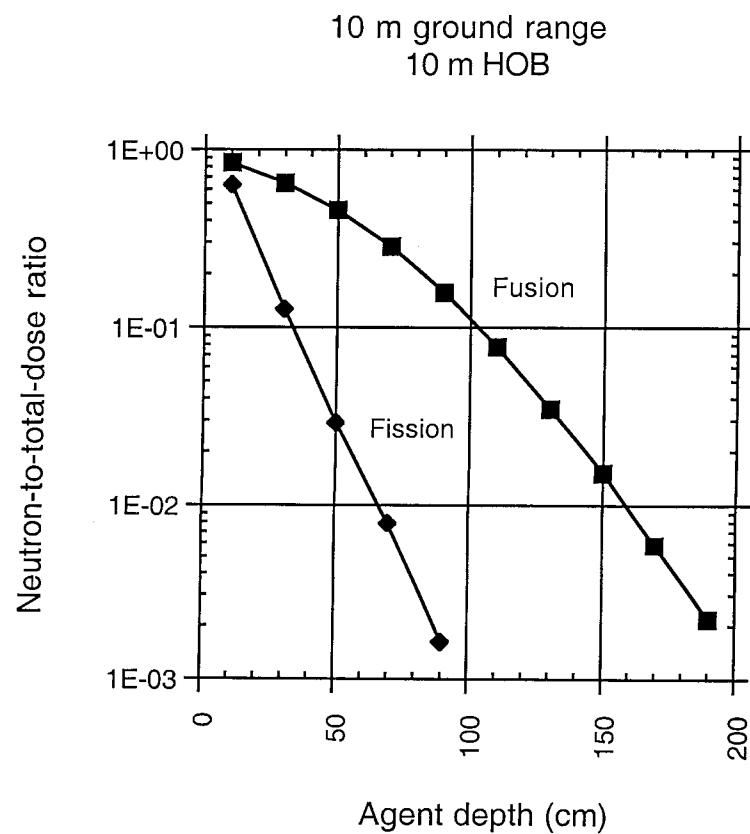
Fig. 19

MCNP Code Geometry for Pyramid Stack of Agent-Filled 200 liter Barrels in a Storage Building

Detonation
at
HOB

20 cm thick
cylindrical
concrete
block walls

4 m high
10 cm thick
concrete roof

50 cm dia.
0.2 cm Fe wall
toroidal barrels

Air

Soil
5 m thick, 1 km radius

R - 5 m

R

R + 5 m
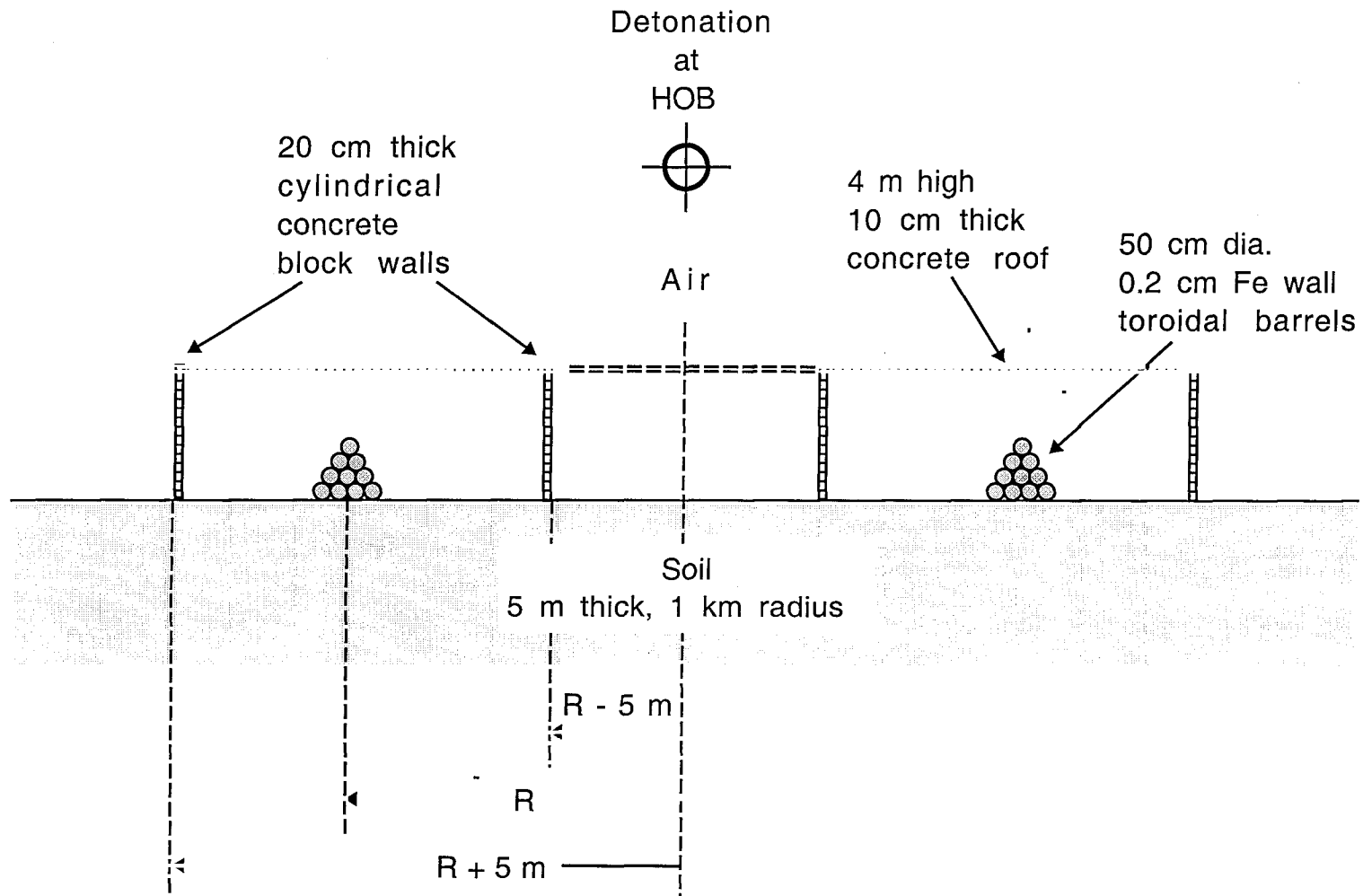
Fig. 20

Lowest Radiation Dose in Barrel Stack from 10 kT Burst at 10 m HOB

Adjacent pyramids of ten 200 liter barrels on the ground
in open air or in a concrete block building

Legend:
- – –◇– – Fusion: open air
- – –✛– – Fission: open air
- ▬ Fusion: in building
- ● Fission: in building

X-axis: Ground range (meters)

Y-axis: Radiation dose (Megarad)
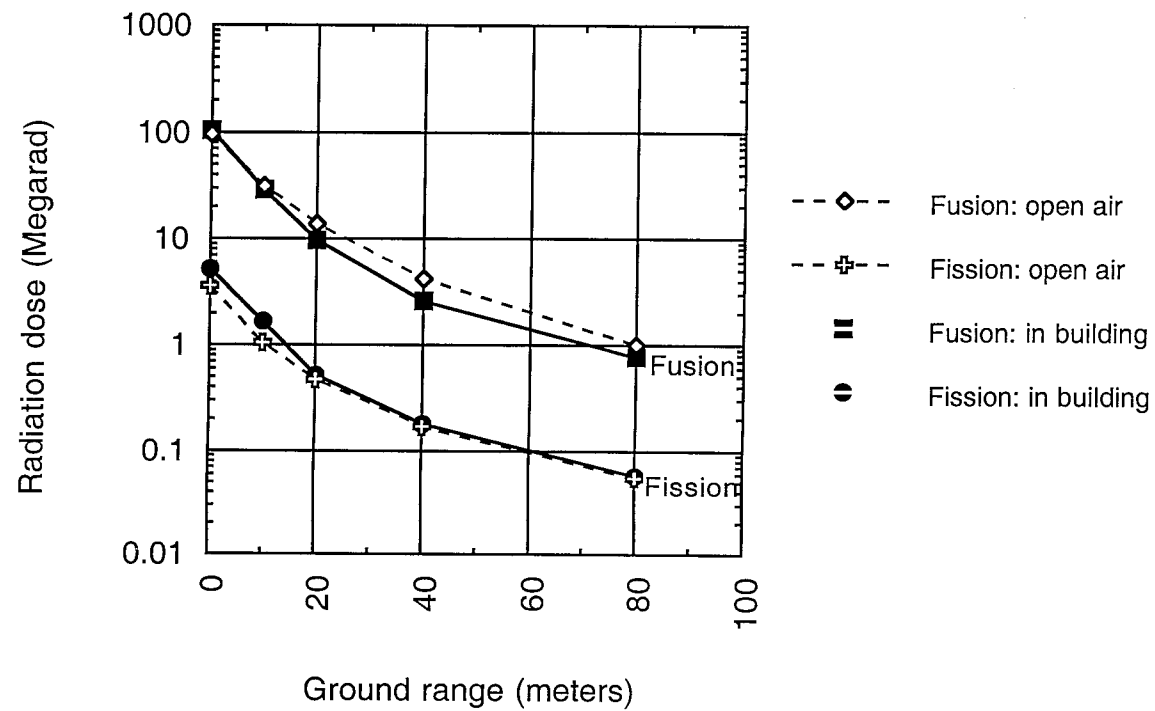
Fig. 21

Fractional Neutron Dose in a Pyramid Stack of 200-Liter Barrels
on the Ground in Open Air

10 m HOB
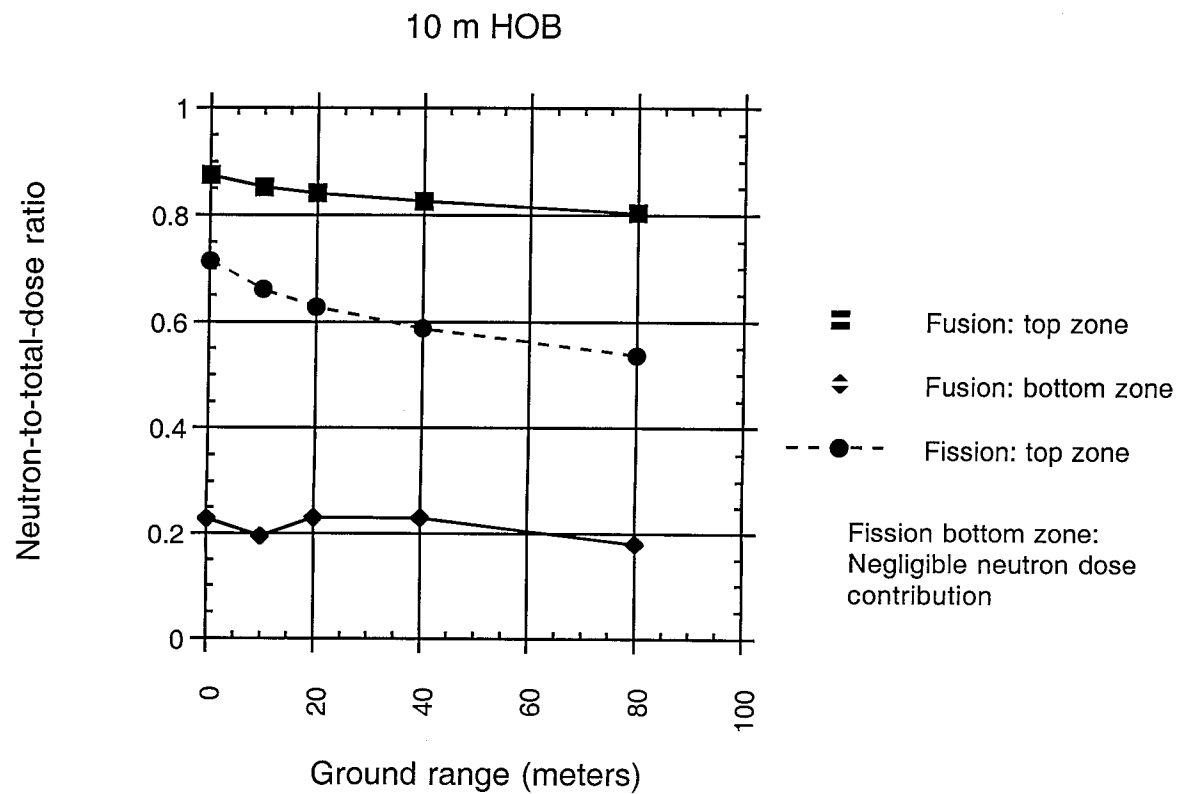
Fig. 22

HOB Dependence of Lowest Radiation Dose in Barrel Stack
from a 10 kT Fission or Fusion Burst

Adjacent pyramids of ten 200 liter barrels on the ground
in open air or in a concrete block building

Height-of-burst (meters)
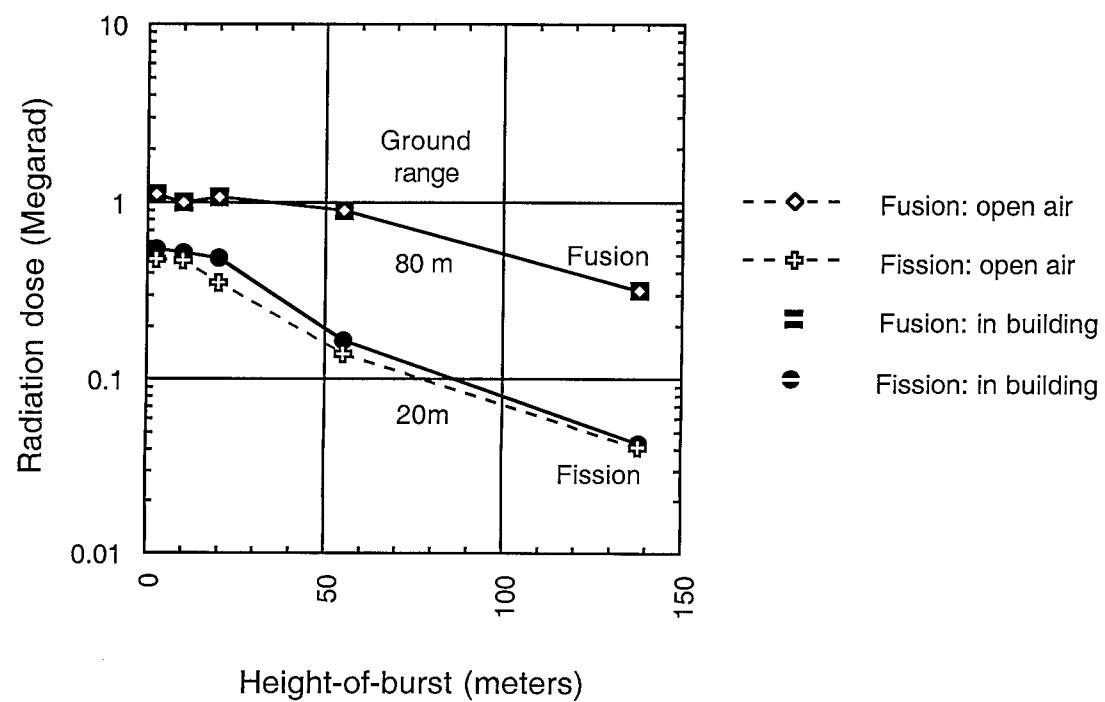
Fig. 23

Radiation Dose in 200-liter Drums inside a Concrete Block Building at a 80 m Ground Range
(Megarad)

Yield: 10 kT   Neutron spectrum: 14 Mev

Fig. A41

55 m HOB
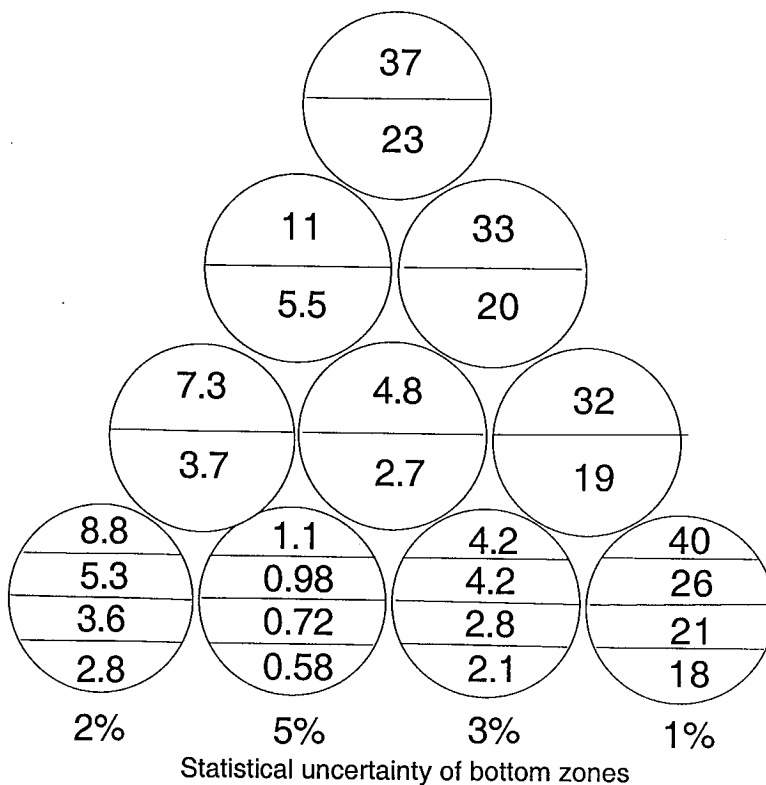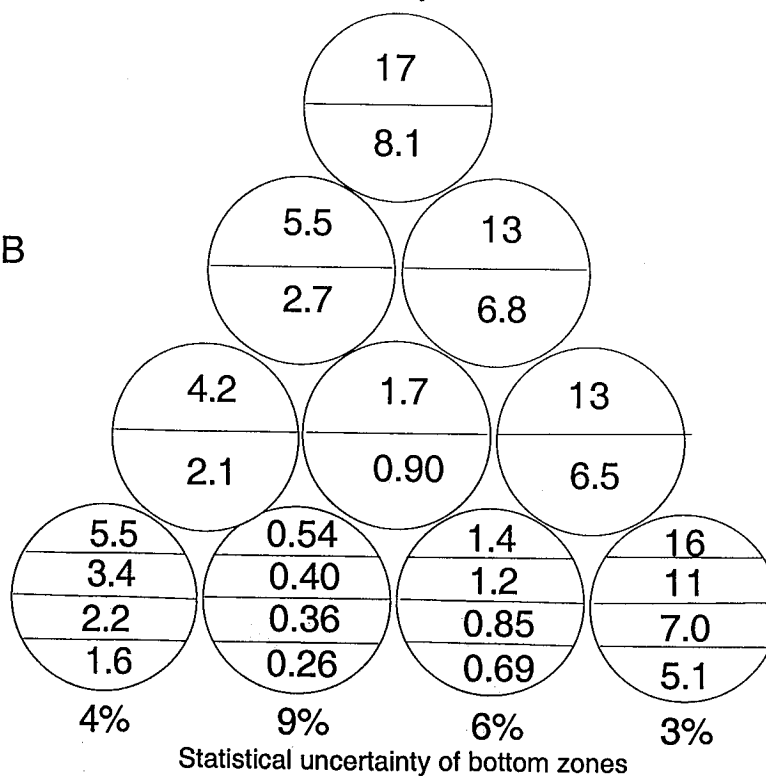
```
                    37
                    23

             11            33
             5.5           20

        7.3       4.8
        3.7       2.7           32
                                19

     8.8     1.1      4.2        40
     5.3     0.98     4.2        26
     3.6     0.72     2.8        21
     2.8     0.58     2.1        18

     2%       5%       3%        1%
```
Statistical uncertainty of bottom zones

Fig. A42

138 m HOB

```
                    17
                    8.1

             5.5           13
             2.7           6.8

        4.2       1.7
        2.1       0.90          13
                                6.5

     5.5     0.54     1.4        16
     3.4     0.40     1.2        11
     2.2     0.36     0.85       7.0
     1.6     0.26     0.69       5.1

     4%       9%       6%        3%
```
Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums inside a Concrete Block Building at a 80 m Ground Range
(Megarad)

Yield: 10 kT   Neutron spectrum: 14 Mev

Fig. A39

2.5 m HOB
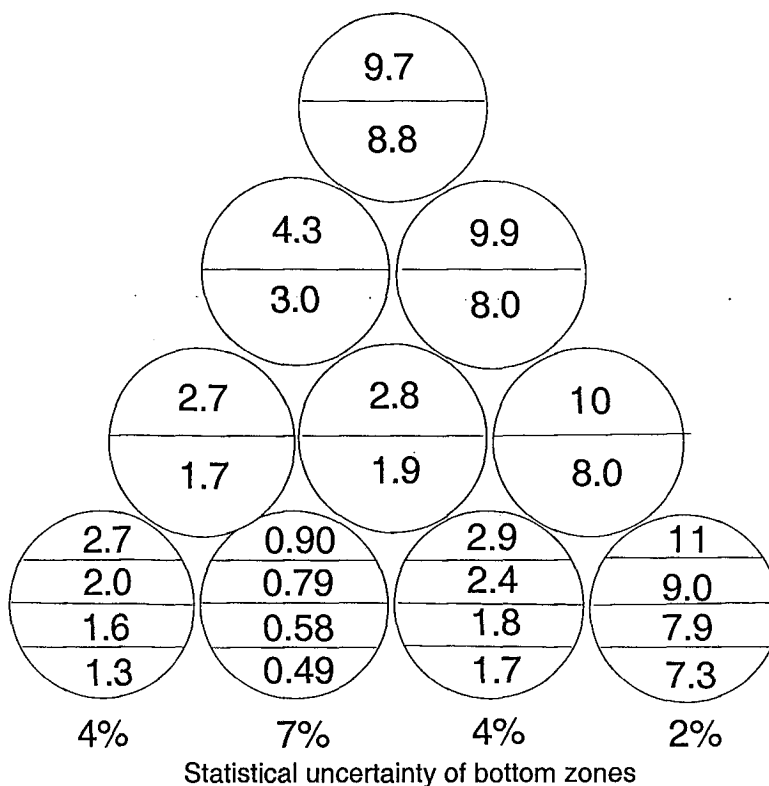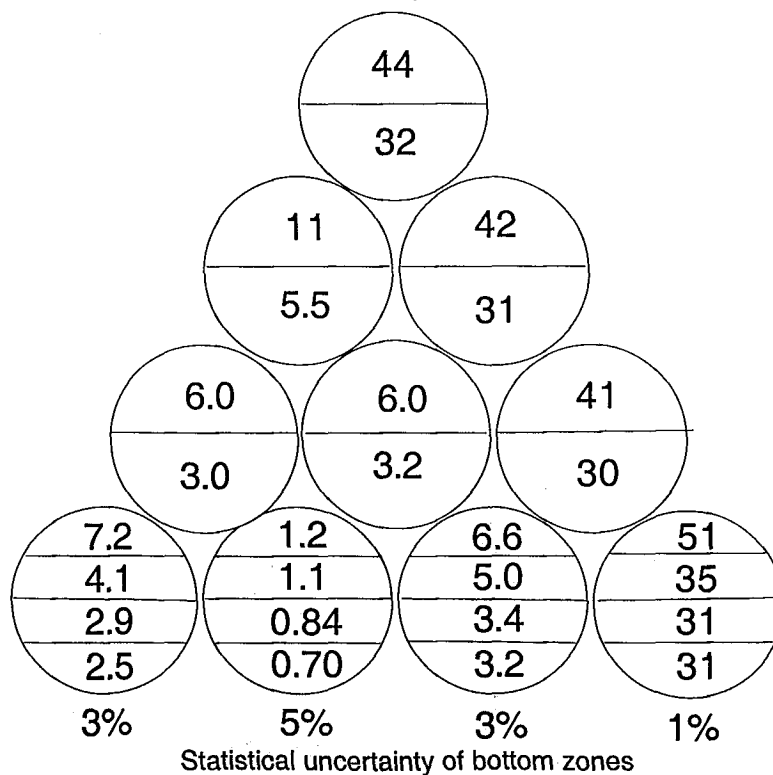
```
                    ┌───────┐
                    │  9.7  │
                    │  8.8  │
                    └───────┘
              ┌───────┐   ┌───────┐
              │  4.3  │   │  9.9  │
              │  3.0  │   │  8.0  │
              └───────┘   └───────┘
        ┌───────┐   ┌───────┐   ┌───────┐
        │  2.7  │   │  2.8  │   │  10   │
        │  1.7  │   │  1.9  │   │  8.0  │
        └───────┘   └───────┘   └───────┘
    ┌──────┐  ┌──────┐  ┌──────┐  ┌──────┐
    │ 2.7  │  │ 0.90 │  │ 2.9  │  │ 11   │
    │ 2.0  │  │ 0.79 │  │ 2.4  │  │ 9.0  │
    │ 1.6  │  │ 0.58 │  │ 1.8  │  │ 7.9  │
    │ 1.3  │  │ 0.49 │  │ 1.7  │  │ 7.3  │
    └──────┘  └──────┘  └──────┘  └──────┘
      4%         7%        4%        2%
```
Statistical uncertainty of bottom zones

Fig. A40

20 m HOB

```
                    ┌───────┐
                    │  44   │
                    │  32   │
                    └───────┘
              ┌───────┐   ┌───────┐
              │  11   │   │  42   │
              │  5.5  │   │  31   │
              └───────┘   └───────┘
        ┌───────┐   ┌───────┐   ┌───────┐
        │  6.0  │   │  6.0  │   │  41   │
        │  3.0  │   │  3.2  │   │  30   │
        └───────┘   └───────┘   └───────┘
    ┌──────┐  ┌──────┐  ┌──────┐  ┌──────┐
    │ 7.2  │  │ 1.2  │  │ 6.6  │  │ 51   │
    │ 4.1  │  │ 1.1  │  │ 5.0  │  │ 35   │
    │ 2.9  │  │ 0.84 │  │ 3.4  │  │ 31   │
    │ 2.5  │  │ 0.70 │  │ 3.2  │  │ 31   │
    └──────┘  └──────┘  └──────┘  └──────┘
      3%         5%        3%        1%
```
Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums inside a Concrete Block Building at 80m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

Fig. A37

14 Mev neutrons
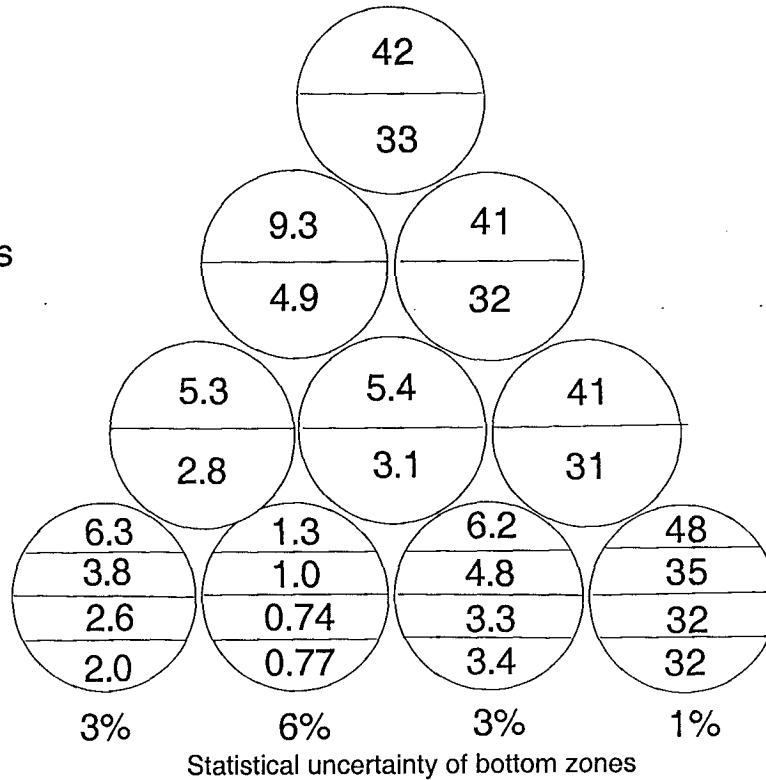
```
                    ┌─────┐
                    │ 42  │
                    │ 33  │
                 ┌─────┐┌─────┐
                 │ 9.3 ││ 41  │
                 │ 4.9 ││ 32  │
              ┌─────┐┌─────┐┌─────┐
              │ 5.3 ││ 5.4 ││ 41  │
              │ 2.8 ││ 3.1 ││ 31  │
           ┌─────┐┌─────┐┌─────┐┌─────┐
           │ 6.3 ││ 1.3 ││ 6.2 ││ 48  │
           │ 3.8 ││ 1.0 ││ 4.8 ││ 35  │
           │ 2.6 ││0.74 ││ 3.3 ││ 32  │
           │ 2.0 ││0.77 ││ 3.4 ││ 32  │
            3%      6%      3%      1%
```

Statistical uncertainty of bottom zones

Fig. A38

Fission neutrons
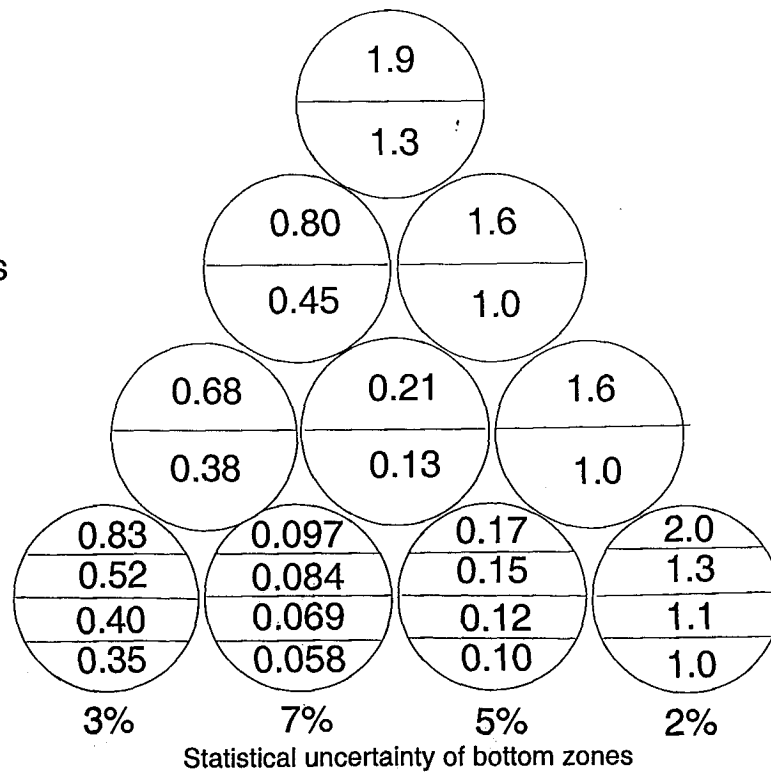
```
                    ┌──────┐
                    │ 1.9  │
                    │ 1.3  │
                 ┌──────┐┌──────┐
                 │ 0.80 ││ 1.6  │
                 │ 0.45 ││ 1.0  │
              ┌──────┐┌──────┐┌──────┐
              │ 0.68 ││ 0.21 ││ 1.6  │
              │ 0.38 ││ 0.13 ││ 1.0  │
           ┌──────┐┌──────┐┌──────┐┌──────┐
           │ 0.83 ││0.097 ││ 0.17 ││ 2.0  │
           │ 0.52 ││0.084 ││ 0.15 ││ 1.3  │
           │ 0.40 ││0.069 ││ 0.12 ││ 1.1  │
           │ 0.35 ││0.058 ││ 0.10 ││ 1.0  │
            3%      7%      5%      2%
```

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums inside a Concrete Block Building at 40 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

Fig. A35

14 Mev neutrons
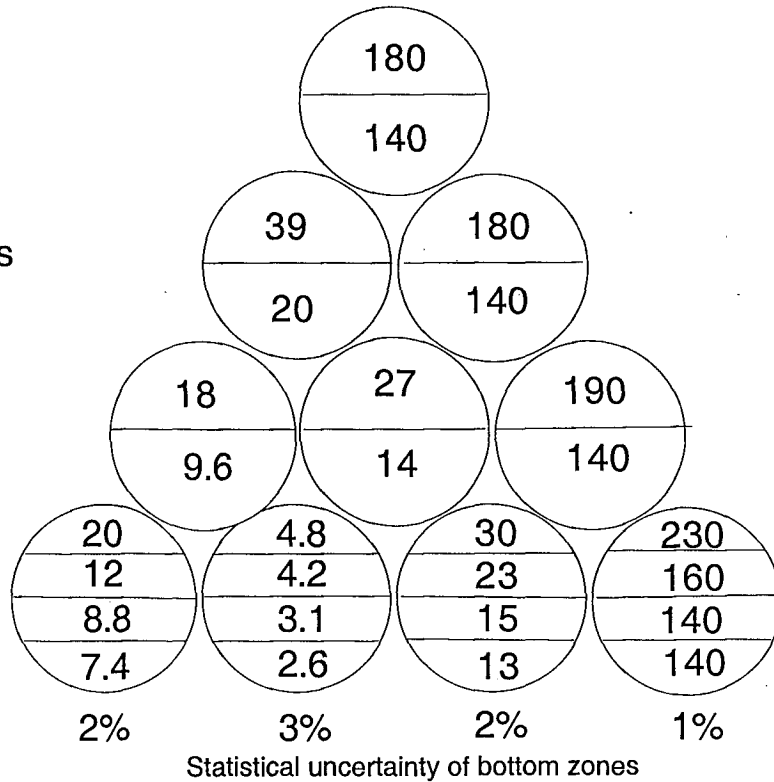
180	
140	

39	180
20	140

18	27	190
9.6	14	140

20	4.8	30	230
12	4.2	23	160
8.8	3.1	15	140
7.4	2.6	13	140

| 2% | 3% | 2% | 1% |

Statistical uncertainty of bottom zones

Fig. A36

Fission neutrons
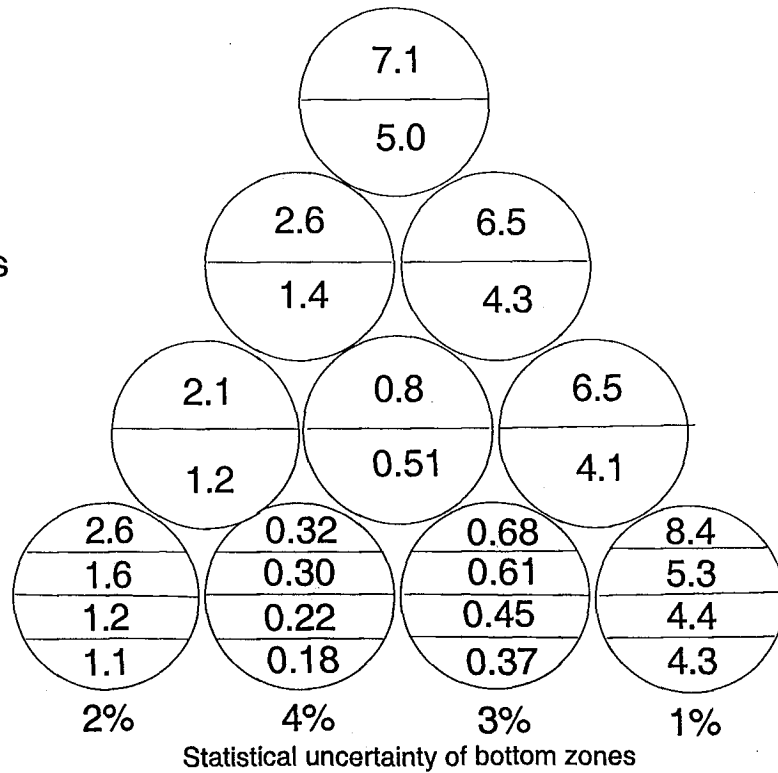
7.1	
5.0	

2.6	6.5
1.4	4.3

2.1	0.8	6.5
1.2	0.51	4.1

2.6	0.32	0.68	8.4
1.6	0.30	0.61	5.3
1.2	0.22	0.45	4.4
1.1	0.18	0.37	4.3

| 2% | 4% | 3% | 1% |

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums inside a Concrete Block Building at 20 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

Fig. A33

14 Mev neutrons
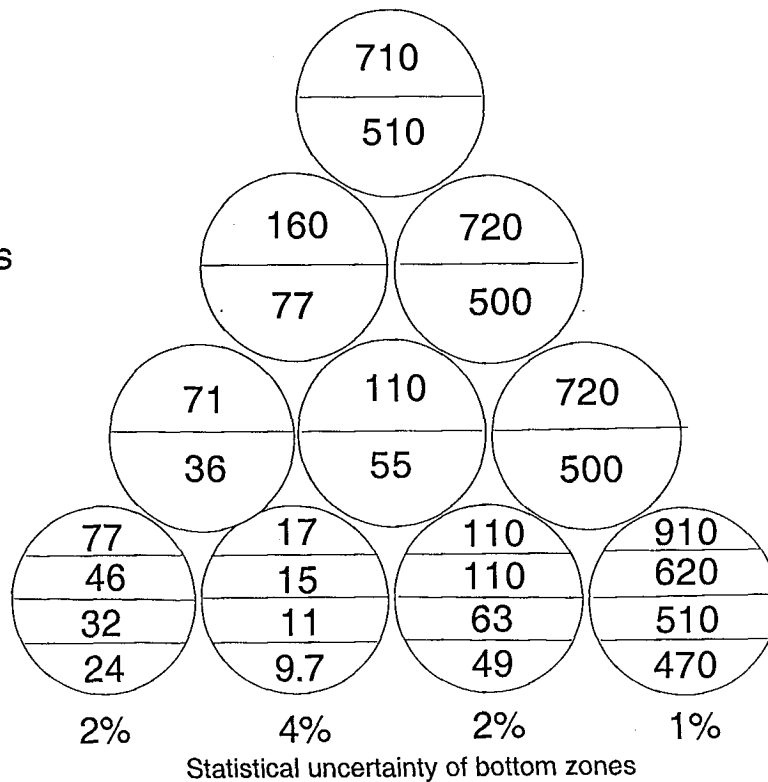
		710 / 510		
	160 / 77		720 / 500	
71 / 36		110 / 55		720 / 500
77 / 46 / 32 / 24	17 / 15 / 11 / 9.7		110 / 110 / 63 / 49	910 / 620 / 510 / 470

2%   4%   2%   1%

Statistical uncertainty of bottom zones

Fig. A34

Fission neutrons
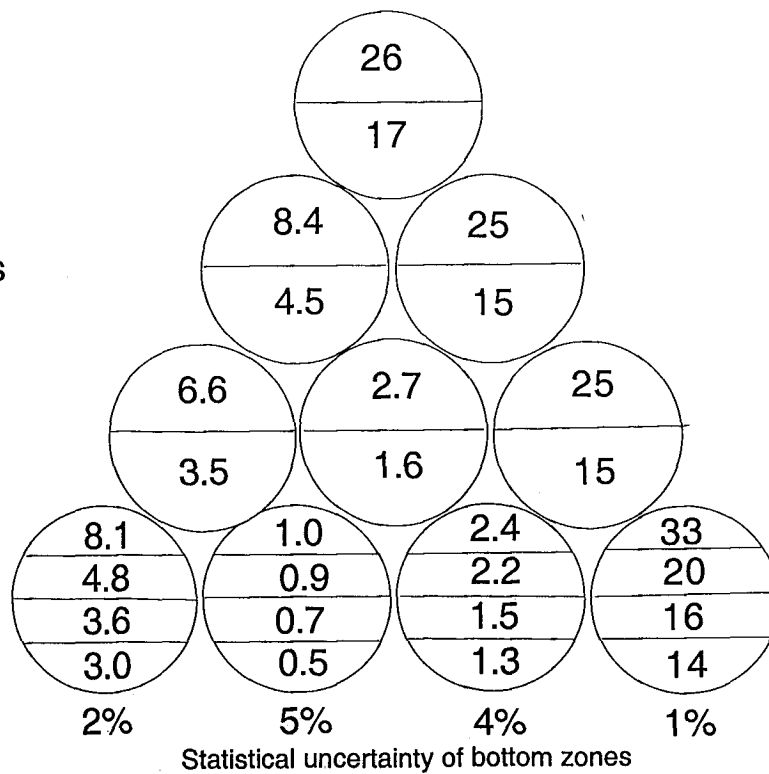
		26 / 17		
	8.4 / 4.5		25 / 15	
6.6 / 3.5		2.7 / 1.6		25 / 15
8.1 / 4.8 / 3.6 / 3.0	1.0 / 0.9 / 0.7 / 0.5		2.4 / 2.2 / 1.5 / 1.3	33 / 20 / 16 / 14

2%   5%   4%   1%

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums inside a Concrete Block Building at 10 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

Fig. A31

14 Mev neutrons
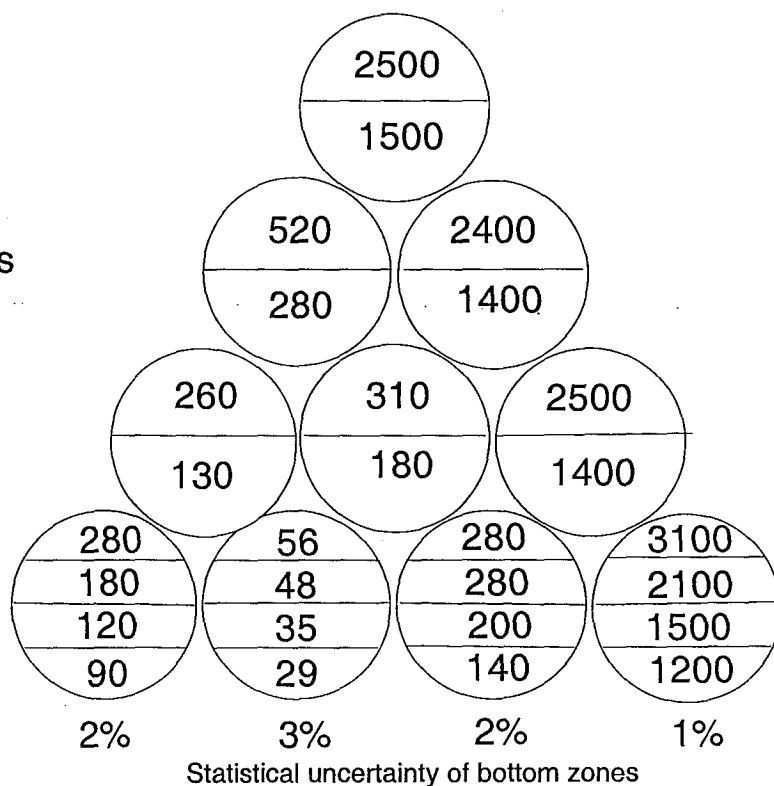
```
                    ┌─────────┐
                    │  2500   │
                    ├─────────┤
                    │  1500   │
                    └─────────┘
              ┌─────────┐ ┌─────────┐
              │   520   │ │  2400   │
              ├─────────┤ ├─────────┤
              │   280   │ │  1400   │
              └─────────┘ └─────────┘
        ┌─────────┐ ┌─────────┐ ┌─────────┐
        │   260   │ │   310   │ │  2500   │
        ├─────────┤ ├─────────┤ ├─────────┤
        │   130   │ │   180   │ │  1400   │
        └─────────┘ └─────────┘ └─────────┘
   ┌───────┐ ┌───────┐ ┌───────┐ ┌───────┐
   │  280  │ │  56   │ │  280  │ │ 3100  │
   │  180  │ │  48   │ │  280  │ │ 2100  │
   │  120  │ │  35   │ │  200  │ │ 1500  │
   │   90  │ │  29   │ │  140  │ │ 1200  │
   └───────┘ └───────┘ └───────┘ └───────┘
     2%         3%         2%        1%
```

Statistical uncertainty of bottom zones

Fig. A32

Fission neutrons
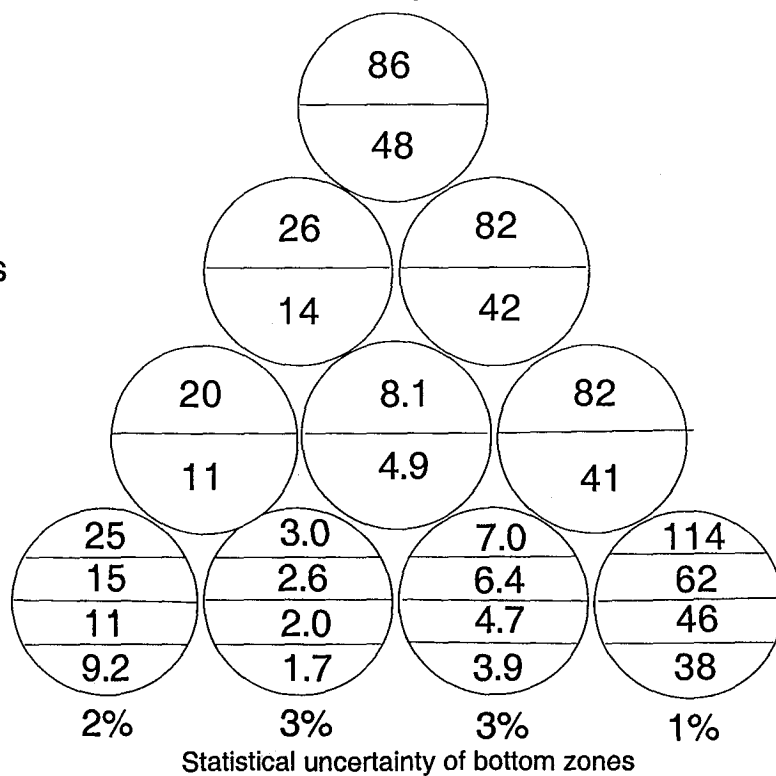
```
                    ┌─────────┐
                    │   86    │
                    ├─────────┤
                    │   48    │
                    └─────────┘
              ┌─────────┐ ┌─────────┐
              │   26    │ │   82    │
              ├─────────┤ ├─────────┤
              │   14    │ │   42    │
              └─────────┘ └─────────┘
        ┌─────────┐ ┌─────────┐ ┌─────────┐
        │   20    │ │   8.1   │ │   82    │
        ├─────────┤ ├─────────┤ ├─────────┤
        │   11    │ │   4.9   │ │   41    │
        └─────────┘ └─────────┘ └─────────┘
   ┌───────┐ ┌───────┐ ┌───────┐ ┌───────┐
   │   25  │ │  3.0  │ │  7.0  │ │  114  │
   │   15  │ │  2.6  │ │  6.4  │ │   62  │
   │   11  │ │  2.0  │ │  4.7  │ │   46  │
   │  9.2  │ │  1.7  │ │  3.9  │ │   38  │
   └───────┘ └───────┘ └───────┘ └───────┘
     2%         3%         3%        1%
```

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums inside a Concrete Block Building underneath the Burst Point (Megarad)

Yield: 10 kT   HOB: 10m

Fig. A29

14 Mev neutrons
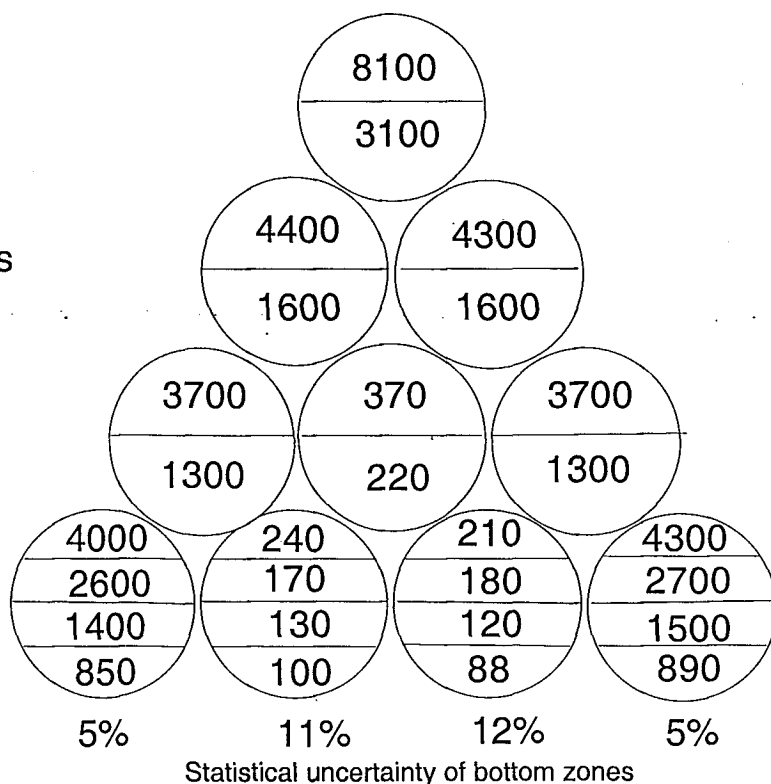
```
                        8100
                        3100

                 4400          4300
                 1600          1600

          3700          370          3700
          1300          220          1300

     4000       240          210       4300
     2600       170          180       2700
     1400       130          120       1500
      850       100           88        890

      5%         11%          12%         5%
```

Statistical uncertainty of bottom zones

Fig. A30

Fission neutrons
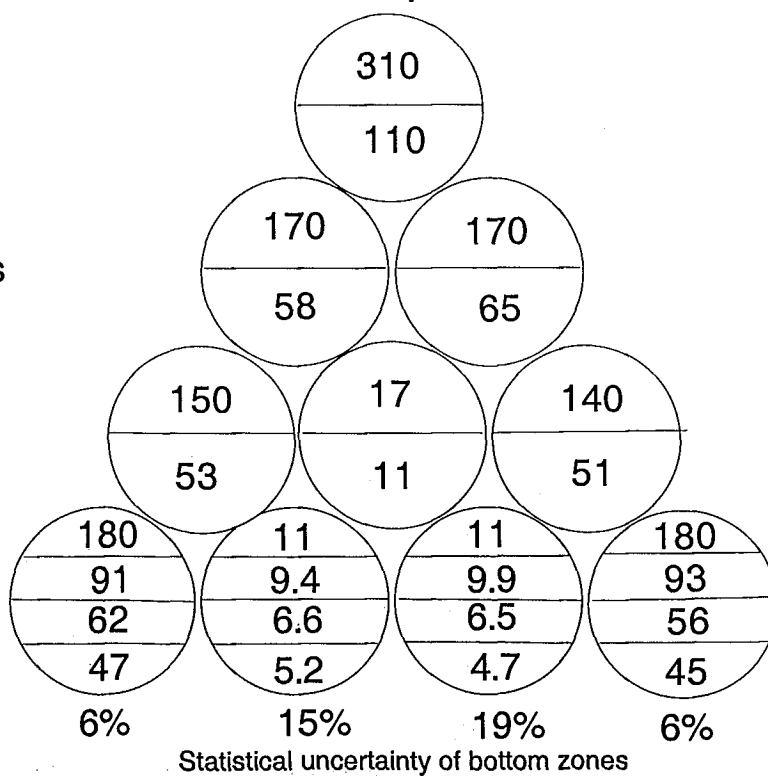
```
                         310
                         110

                  170          170
                   58           65

           150           17          140
            53           11           51

     180         11           11         180
      91        9.4          9.9         93
      62        6.6          6.5         56
      47        5.2          4.7         45

      6%         15%          19%         6%
```

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air at a 10 m Ground Range
(Megarad)

Neutron yield: 25 moles   HOB: 10m

Fig. A27

100 ev neutrons

330	
250	

100	360
66	230

76	49	360
48	30	220

87	17	47	450
57	15	39	300
47	10	28	240
40	8.9	24	220

2%   4%   3%   1%

Statistical uncertainty of bottom zones

Fig. A28

10 ev neutrons

340	
250	

110	380
69	230

78	49	370
49	32	230

88	17	48	460
57	14	41	300
45	10	31	240
41	9.2	24	220

2%   4%   3%   1%

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air
at a 10 m Ground Range
(Megarad)

Neutron yield: 25 moles   HOB: 10m

Fig. A25

10 Kev neutrons

```
                    310
                    ───
                    230

              96          350
              ──          ───
              61          220

         69        45         350
         ──        ──         ───
         43        28         210

     74      14       43       440
     51      12       38       280
     42      9.3      28       230
     37      7.6      22       210

     2%      5%       3%       1%
```

Statistical uncertainty of bottom zones

Fig. A26

1 Kev neutrons

```
                    320
                    ───
                    240

             110          350
             ───          ───
              64          220

         74        47         350
         ──        ──         ───
         46        29         220

     83      15       44       440
     57      13       39       290
     47      10       30       230
     40      8.4      23       220

     2%      4%       3%       1%
```

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air
at a 10 m Ground Range
(Megarad)

Neutron yield: 25 moles

HOB: 10m

Fig. A23

1 Mev neutrons

720
360

110 / 66

740 / 330

81 / 44

45 / 27

730 / 310

93 / 51 / 38 / 30

12 / 10 / 7.5 / 6.1

45 / 39 / 28 / 22

1100 / 490 / 350 / 290

2%   5%   3%   0.8%

Statistical uncertainty of bottom zones

Fig. A24

0.1 Mev neutrons

340
230

86 / 54

390 / 220

56 / 35

45 / 27

380 / 220

62 / 41 / 32 / 27

13 / 11 / 7.8 / 6.3

43 / 37 / 27 / 22

490 / 300 / 230 / 210

2%   5%   3%   1%

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air
at a 10 m Ground Range
(Megarad)

Neutron yield: 25 moles   HOB: 10m

Fig. A21

6 Mev neutrons

```
                    2500
                    ────
                    1200

            240           2500
            ───           ────
            120           1200

      93          160           2500
      ──          ───           ────
      51          75            1100

   94       18        140        3400
   55       15        140        1900
   37       11        88         1300
   27       8.2       62         950

   3%       4%        2%        0.7%
```
Statistical uncertainty of bottom zones

Fig. A22

3 Mev neutrons

```
                    150
                    ───
                    72

            14            160
            ──            ───
            7.2           69

      7.0         8.4           160
      ───         ───           ───
      3.6         4.3           66

   7.8      1.4       8.0        230
   4.2      1.2       7.4        110
   2.8      0.83      4.8        76
   2.2      0.69      3.6        56

   3%       5%        2%        0.7%
```
Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air
at a 10 m Ground Range
(Megarad)

Neutron yield: 25 moles   HOB: 10m

Fig. A19

20 Mev neutrons

```
                    ┌─────────┐
                    │  4500   │
                    │  3000   │
                    └─────────┘
              ┌─────────┐ ┌─────────┐
              │   890   │ │  4800   │
              │   580   │ │  3000   │
              └─────────┘ └─────────┘
         ┌─────────┐ ┌─────────┐ ┌─────────┐
         │   170   │ │   860   │ │  4800   │
         │    99   │ │   550   │ │  2900   │
         └─────────┘ └─────────┘ └─────────┘
    ┌──────┐ ┌──────┐ ┌──────┐ ┌──────┐
    │  86  │ │ 130  │ │ 820  │ │ 5700 │
    │  58  │ │ 110  │ │ 790  │ │ 4100 │
    │  41  │ │  74  │ │ 610  │ │ 3200 │
    │  29  │ │  59  │ │ 440  │ │ 2500 │
    └──────┘ └──────┘ └──────┘ └──────┘
      3%       3%       1%      0.5%
```

Statistical uncertainty of bottom zones

Fig. A20

10 Mev neutrons

```
                    ┌─────────┐
                    │  3300   │
                    │  1800   │
                    └─────────┘
              ┌─────────┐ ┌─────────┐
              │   400   │ │  3400   │
              │   230   │ │  1800   │
              └─────────┘ └─────────┘
         ┌─────────┐ ┌─────────┐ ┌─────────┐
         │   110   │ │   330   │ │  3400   │
         │    67   │ │   180   │ │  1700   │
         └─────────┘ └─────────┘ └─────────┘
    ┌──────┐ ┌──────┐ ┌──────┐ ┌──────┐
    │ 100  │ │  41  │ │ 310  │ │ 4300 │
    │  63  │ │  34  │ │ 300  │ │ 2700 │
    │  42  │ │  26  │ │ 200  │ │ 1900 │
    │  30  │ │  19  │ │ 140  │ │ 1400 │
    └──────┘ └──────┘ └──────┘ └──────┘
      3%       3%       2%      0.6%
```

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air at a 20 m Ground Range
(Megarad)

Yield: 10 kT   Neutron spectrum: Fission

Fig. A17

55 m HOB

```
              ┌──────┐
              │  10  │
              │  3.7 │
           ┌─────┐ ┌─────┐
           │ 3.3 │ │ 7.5 │
           │ 1.4 │ │ 2.8 │
        ┌─────┐ ┌──────┐ ┌─────┐
        │ 3.2 │ │ 0.56 │ │ 7.4 │
        │ 1.3 │ │ 0.35 │ │ 2.7 │
     ┌─────┐ ┌──────┐ ┌──────┐ ┌─────┐
     │ 4.2 │ │ 0.27 │ │ 0.45 │ │ 11  │
     │ 2.3 │ │ 0.23 │ │ 0.40 │ │ 5.3 │
     │ 1.6 │ │ 0.17 │ │ 0.29 │ │ 3.2 │
     │ 1.2 │ │ 0.14 │ │ 0.24 │ │ 2.3 │
      3%       8%       6%       2%
```
Statistical uncertainty of bottom zones

Fig. A18

138 m HOB

```
              ┌──────┐
              │  1.9 │
              │ 0.79 │
           ┌─────┐ ┌─────┐
           │ 1.0 │ │ 1.2 │
           │ 0.40│ │ 0.49│
        ┌──────┐ ┌───────┐ ┌─────┐
        │ 0.97 │ │ 0.12  │ │ 1.2 │
        │ 0.39 │ │ 0.074 │ │ 0.51│
     ┌──────┐ ┌───────┐ ┌───────┐ ┌─────┐
     │ 1.3  │ │ 0.085 │ │ 0.095 │ │ 1.7 │
     │ 0.64 │ │ 0.073 │ │ 0.079 │ │ 0.84│
     │ 0.43 │ │ 0.042 │ │ 0.048 │ │ 0.49│
     │ 0.34 │ │ 0.041 │ │ 0.037 │ │ 0.40│
      6%       15%       16%       6%
```
Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air at a 20 m Ground Range
(Megarad)

Yield: 10 kT   Neutron spectrum: Fission

Fig. A15

2.5 m HOB

```
                    50
                    41

              6.6         56
              3.7         41

         4.0       3.9         57
         2.1       2.3         43

    4.8       0.84      4.3        71
    2.7       0.74      3.6        49
    1.9       0.56      2.7        45
    1.6       0.48      2.5        50

    2%         5%        2%       0.6%
```
Statistical uncertainty of bottom zones

Fig. A16

20 m HOB

```
                    37
                    18

              6.2         37
              3.4         17

         4.3       2.5         36
         2.3       1.5         16

    5.3       0.64      2.4        52
    3.0       0.54      2.2        26
    2.3       0.44      1.5        19
    1.8       0.35      1.2        15

    2%         5%        3%        1%
```
Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air
at a 80 m Ground Range
(Megarad)

Yield: 10 kT   Neutron spectrum: 14 Mev

Fig. A13

55 m HOB
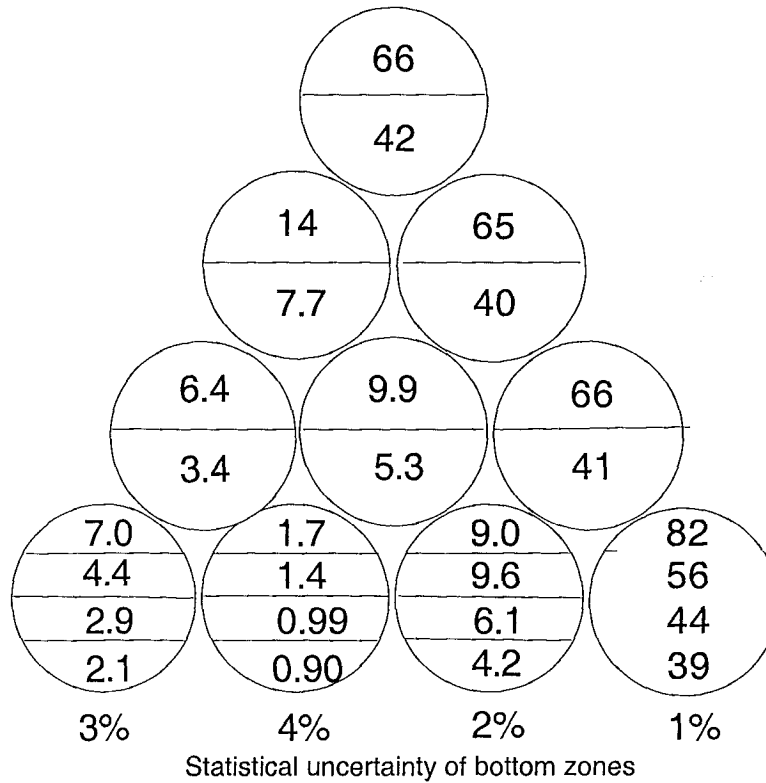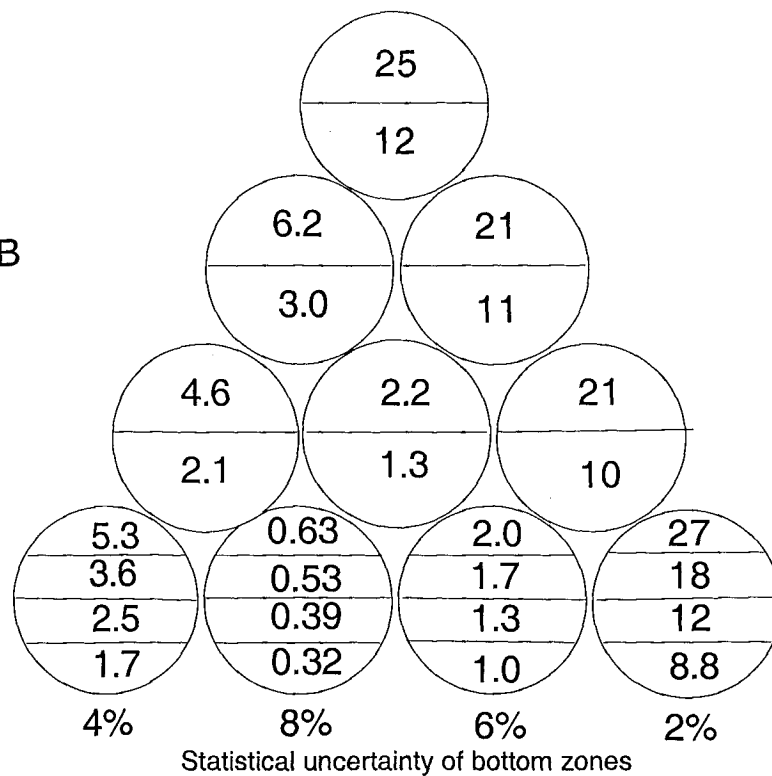
	66
	42

14		65
7.7		40

6.4	9.9	66
3.4	5.3	41

7.0	1.7	9.0	82
4.4	1.4	9.6	56
2.9	0.99	6.1	44
2.1	0.90	4.2	39

3%   4%   2%   1%

Statistical uncertainty of bottom zones

Fig. A14

138 m HOB

	25
	12

6.2		21
3.0		11

4.6	2.2	21
2.1	1.3	10

5.3	0.63	2.0	27
3.6	0.53	1.7	18
2.5	0.39	1.3	12
1.7	0.32	1.0	8.8

4%   8%   6%   2%

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air
at a 80 m Ground Range
(Megarad)

Yield: 10 kT   Neutron spectrum: 14 Mev

Fig. A11

2.5 m HOB
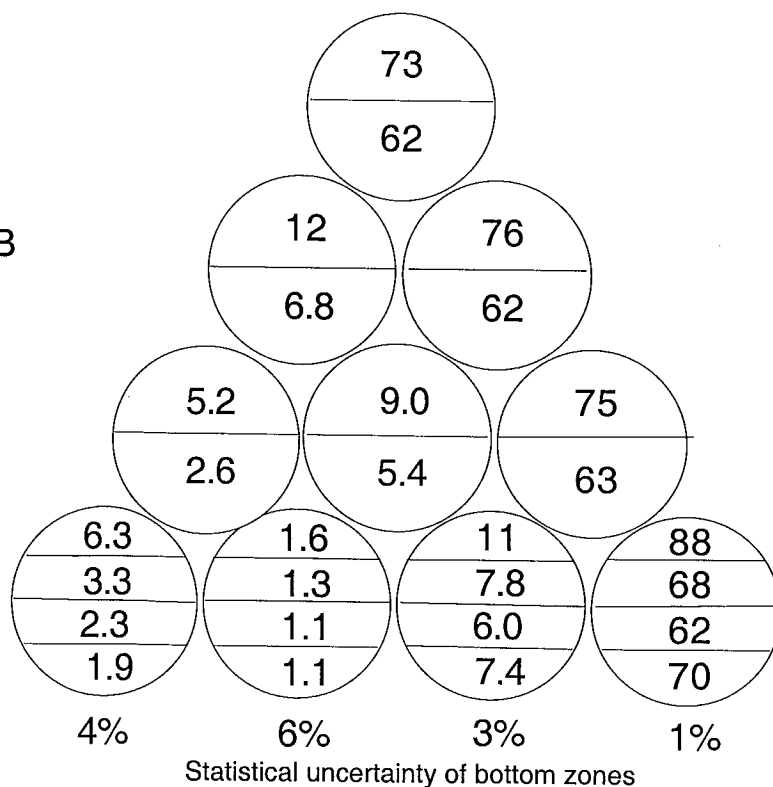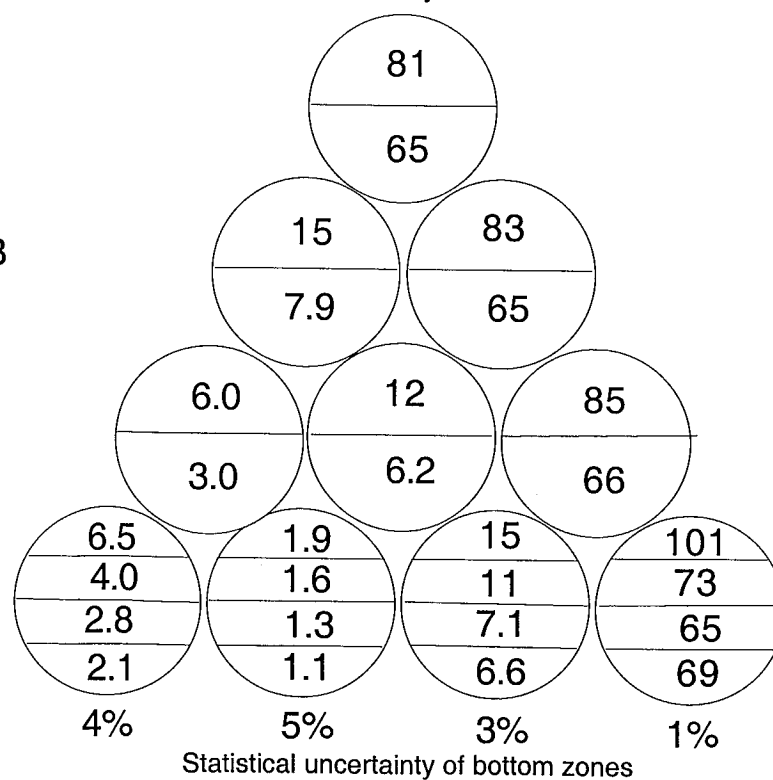
73
62

12 / 6.8   76 / 62

5.2 / 2.6   9.0 / 5.4   75 / 63

6.3 / 3.3 / 2.3 / 1.9   1.6 / 1.3 / 1.1 / 1.1   11 / 7.8 / 6.0 / 7.4   88 / 68 / 62 / 70

4%   6%   3%   1%

Statistical uncertainty of bottom zones

Fig. A12

20 m HOB

81
65

15 / 7.9   83 / 65

6.0 / 3.0   12 / 6.2   85 / 66

6.5 / 4.0 / 2.8 / 2.1   1.9 / 1.6 / 1.3 / 1.1   15 / 11 / 7.1 / 6.6   101 / 73 / 65 / 69

4%   5%   3%   1%

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air at a 80 m Ground Range (Megarad)

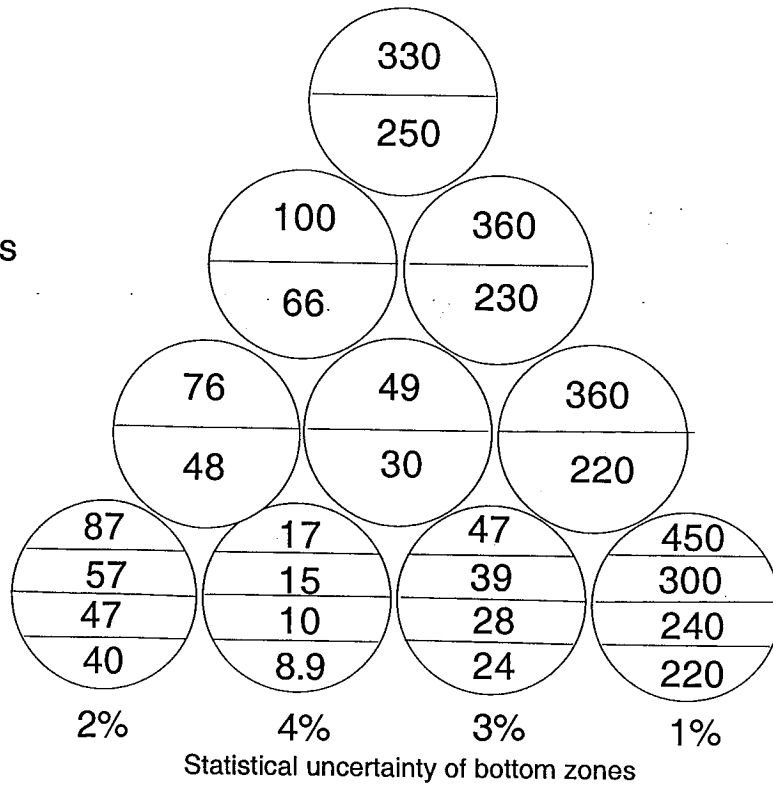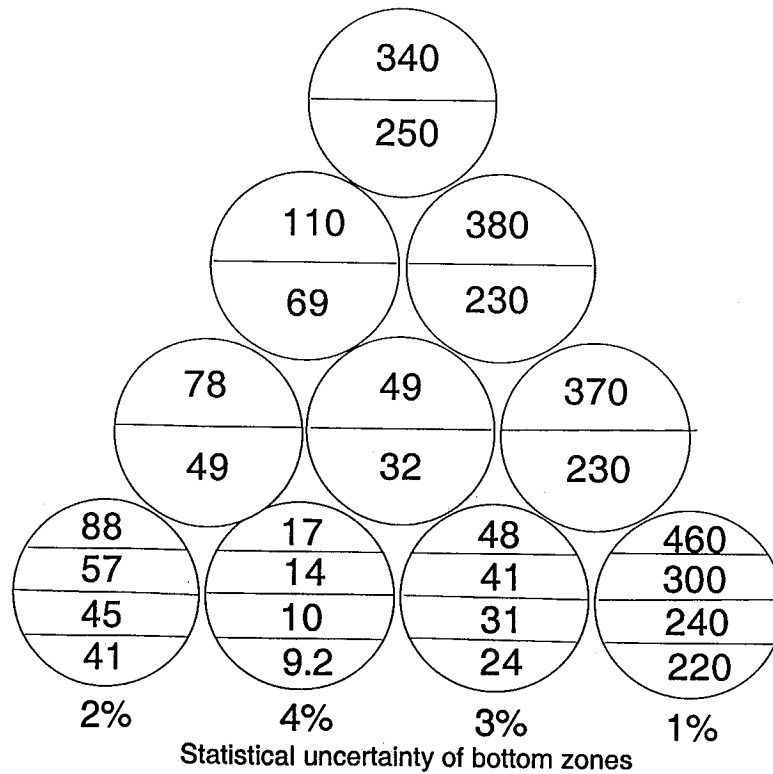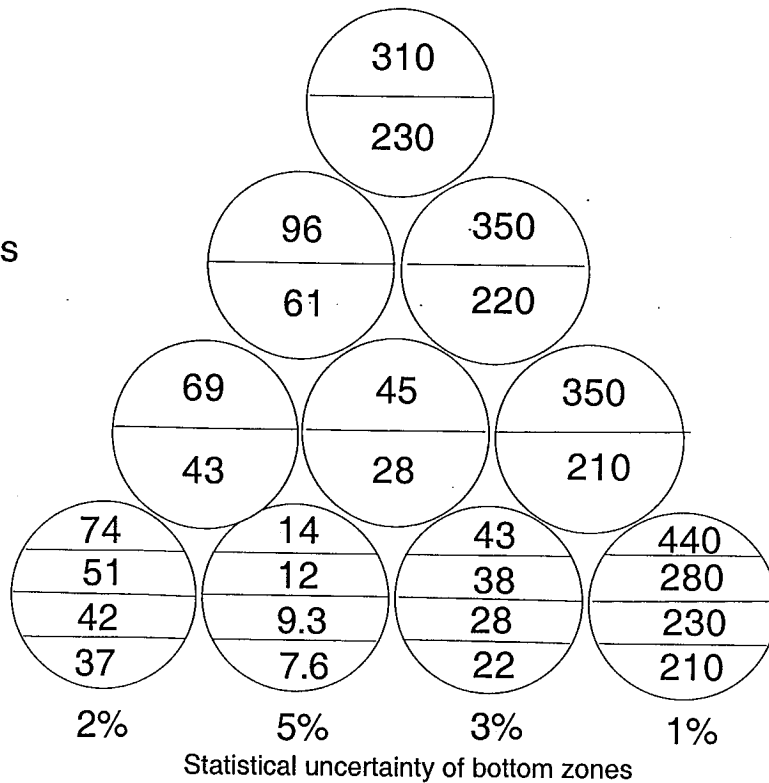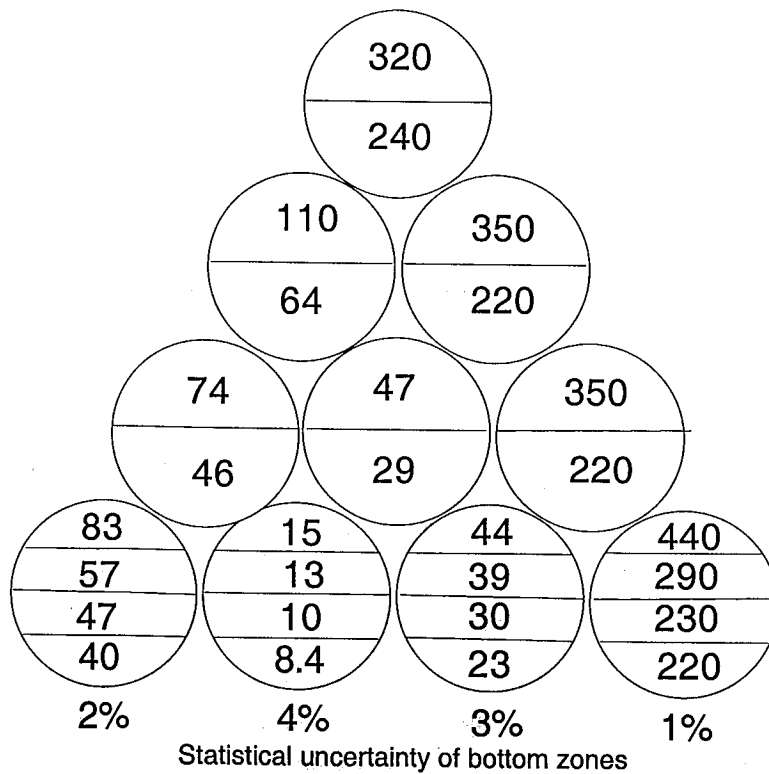Yield: 10 kT   HOB: 10m

Fig. A9

14 Mev neutrons
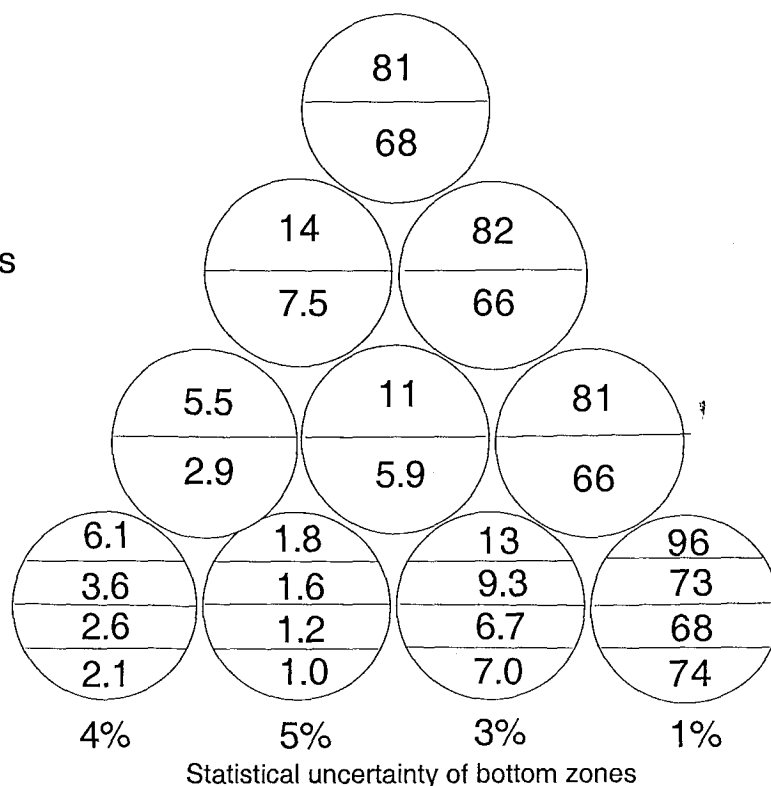
```
                81
                68

          14          82
          7.5         66

      5.5      11        81
      2.9      5.9       66

   6.1    1.8     13     96
   3.6    1.6     9.3    73
   2.6    1.2     6.7    68
   2.1    1.0     7.0    74

   4%     5%      3%     1%
```
Statistical uncertainty of bottom zones

Fig. A10

Fission neutrons
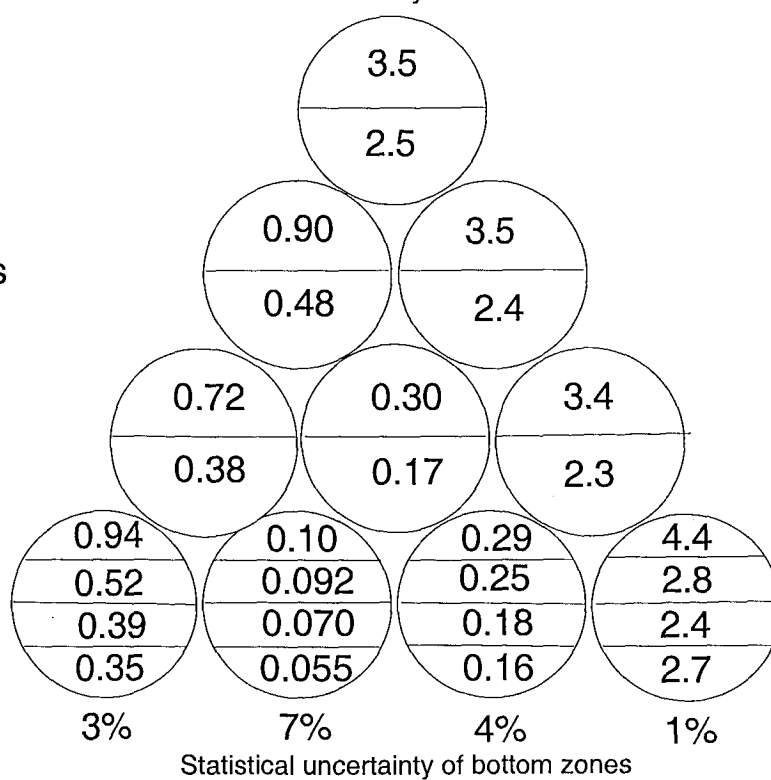
```
                3.5
                2.5

          0.90        3.5
          0.48        2.4

      0.72     0.30      3.4
      0.38     0.17      2.3

   0.94    0.10    0.29    4.4
   0.52    0.092   0.25    2.8
   0.39    0.070   0.18    2.4
   0.35    0.055   0.16    2.7

   3%      7%      4%      1%
```
Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air at a 40 m Ground Range (Megarad)

Yield: 10 kT   HOB: 10m

Fig. A7

14 Mev neutrons
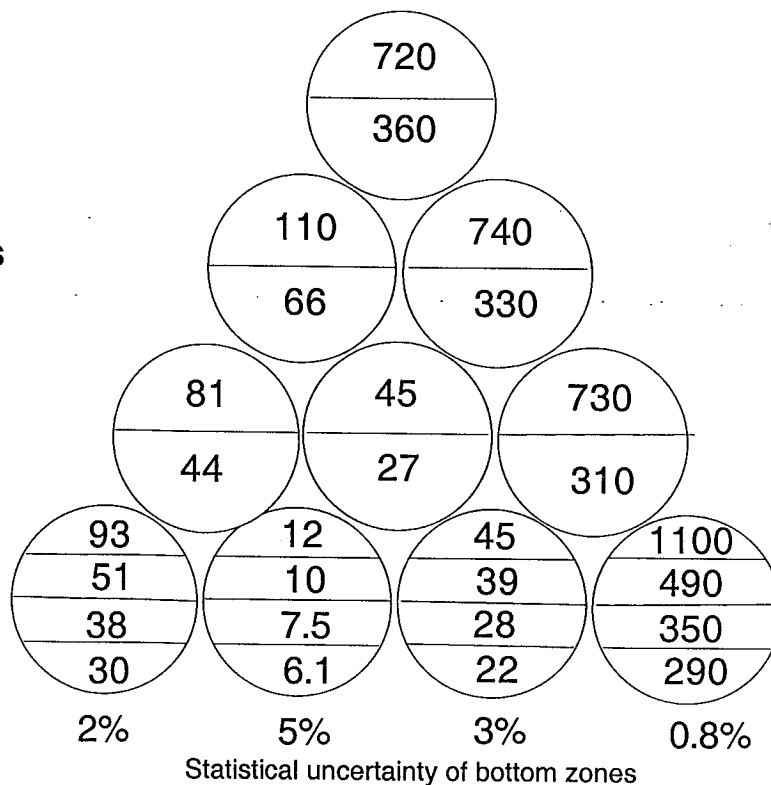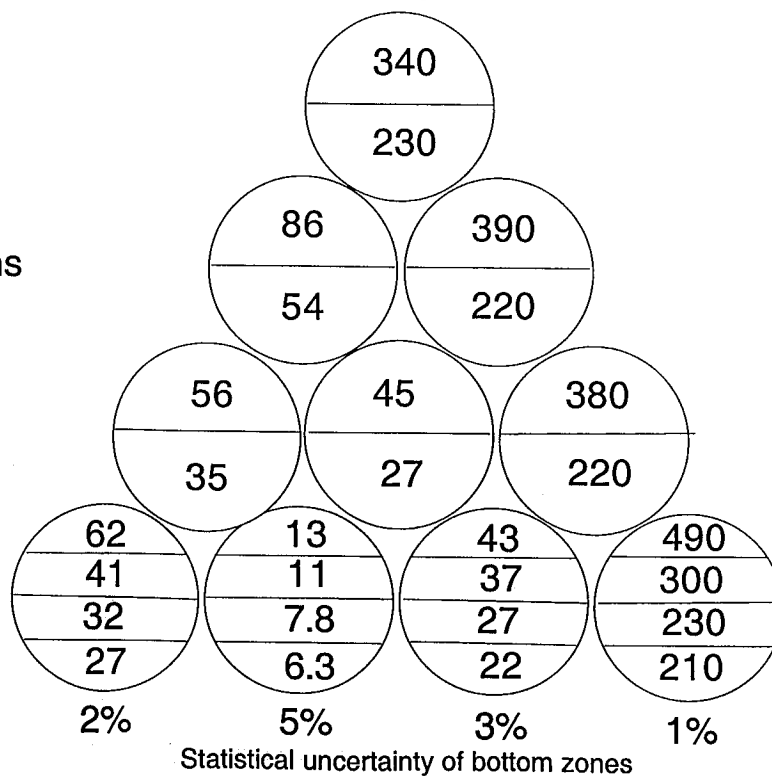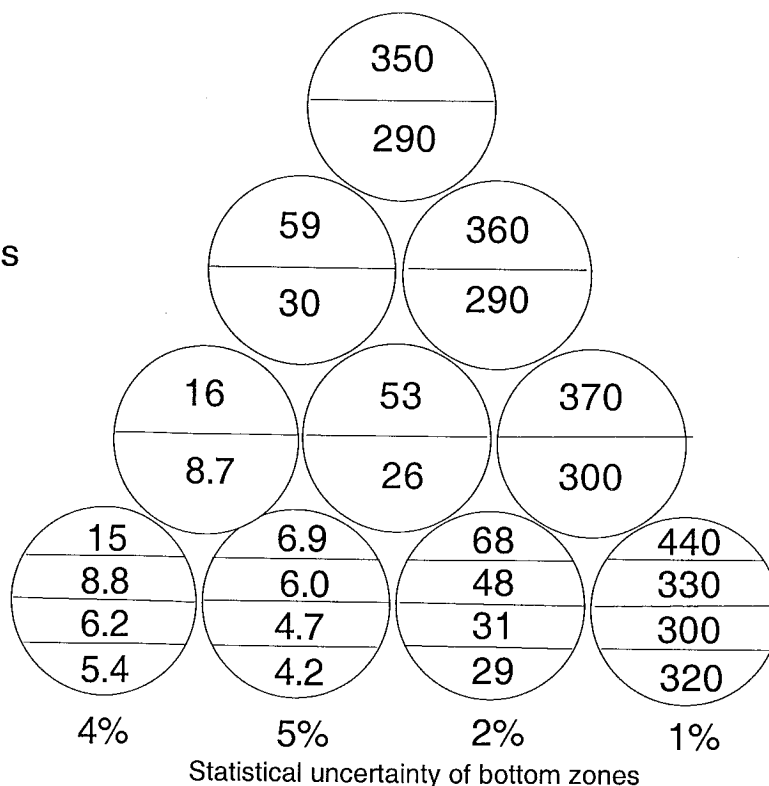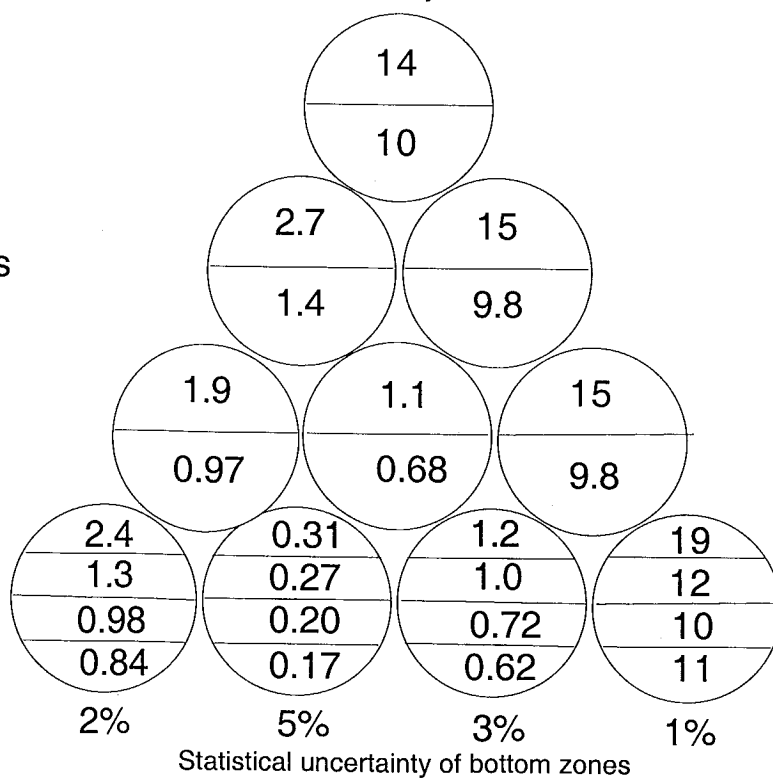
350		
290		

59		360
30		290

16	53	370
8.7	26	300

15	6.9	68	440
8.8	6.0	48	330
6.2	4.7	31	300
5.4	4.2	29	320

| 4% | 5% | 2% | 1% |

Statistical uncertainty of bottom zones

Fig. A8

Fission neutrons

14		
10		

2.7		15
1.4		9.8

1.9	1.1	15
0.97	0.68	9.8

2.4	0.31	1.2	19
1.3	0.27	1.0	12
0.98	0.20	0.72	10
0.84	0.17	0.62	11

| 2% | 5% | 3% | 1% |

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air
at a 20 m Ground Range
(Megarad)

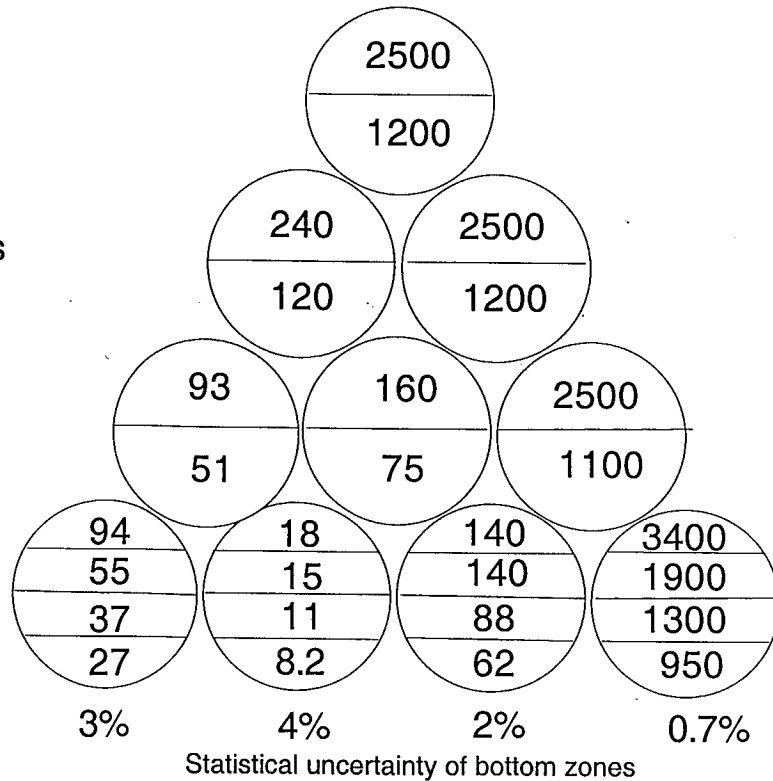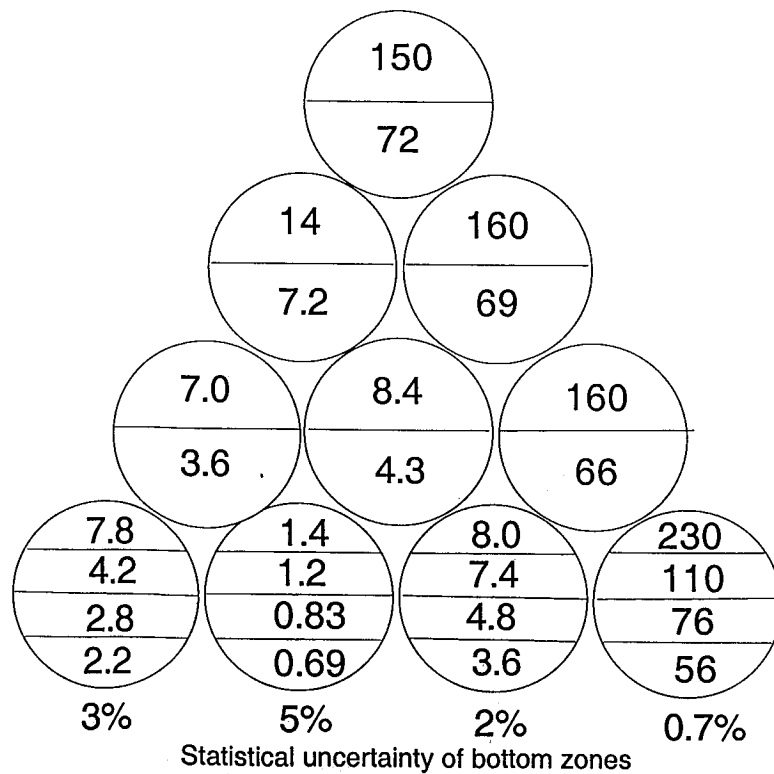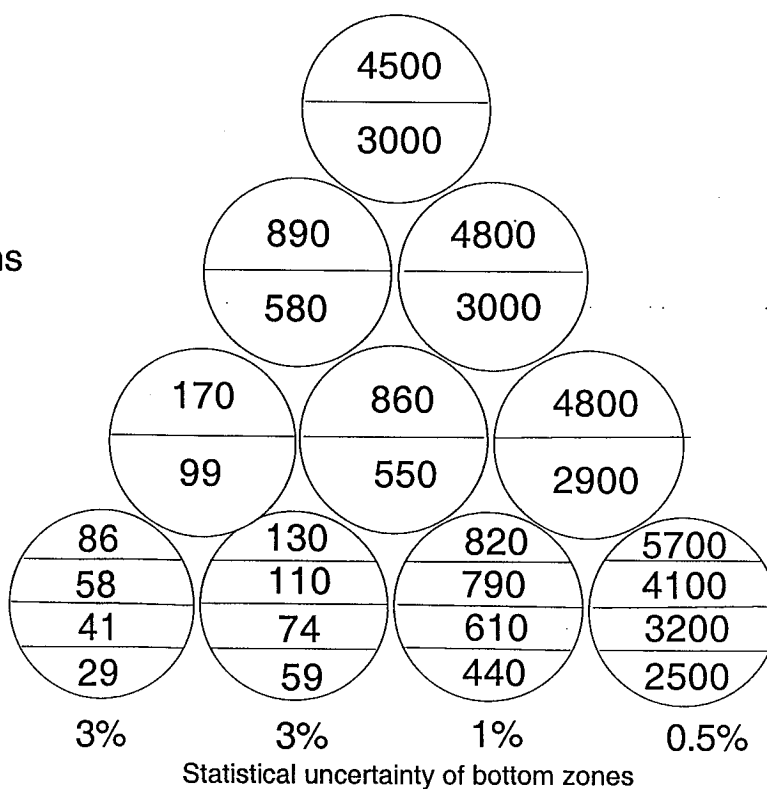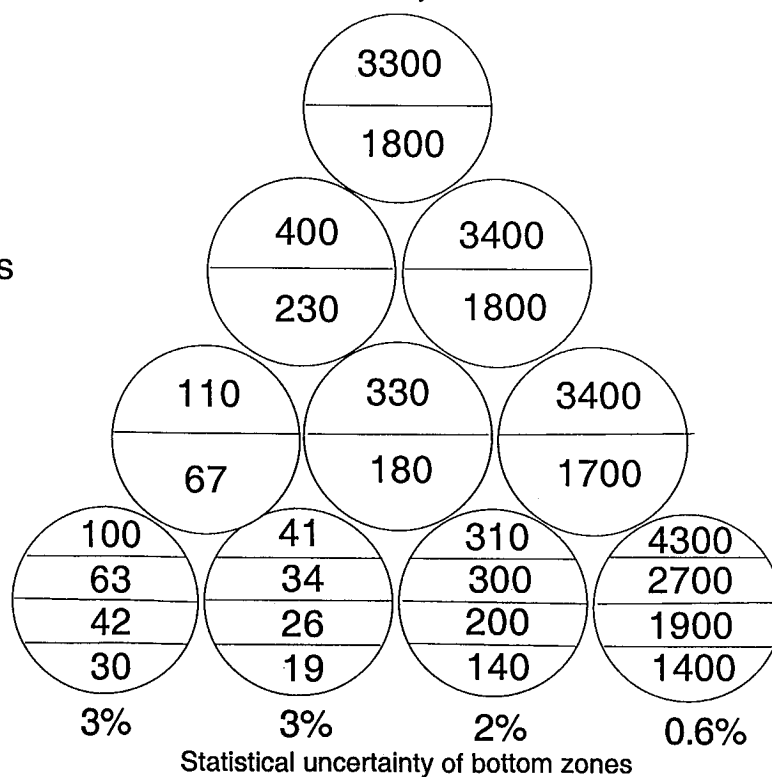Yield: 10 kT   HOB: 10m

Fig. A5

14 Mev neutrons
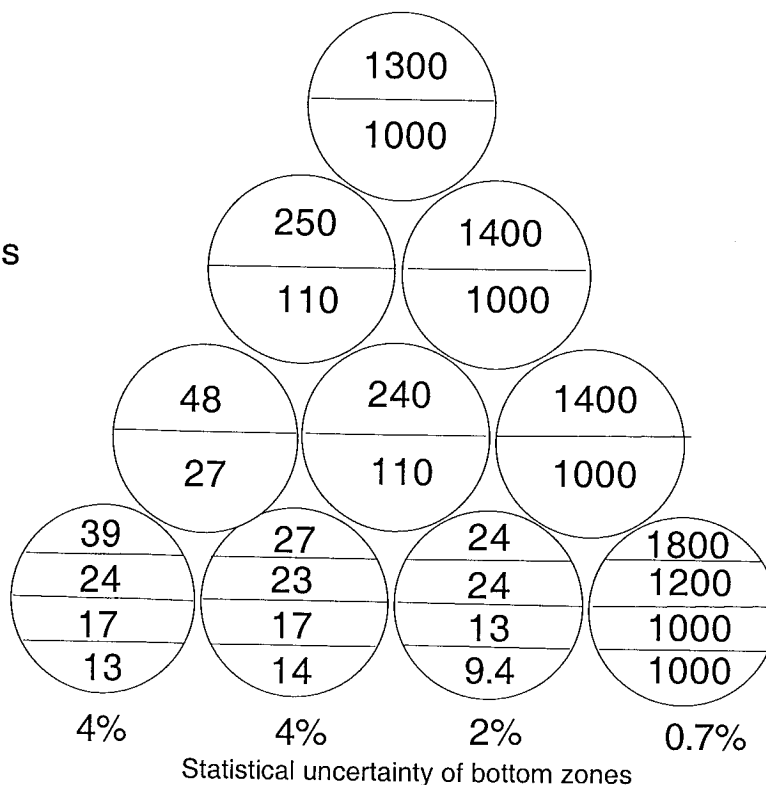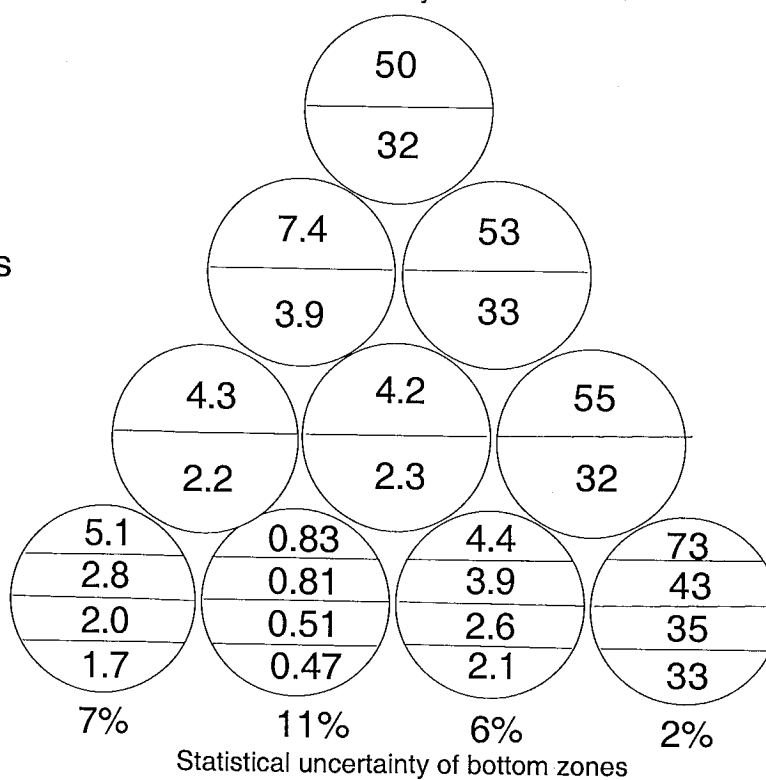
```
                            1300
                            1000

                    250             1400
                    110             1000

              48          240             1400
              27          110             1000

         39        27          24        1800
         24        23          24        1200
         17        17          13        1000
         13        14          9.4       1000
         4%        4%          2%        0.7%
```
Statistical uncertainty of bottom zones

Fig. A6

Fission neutrons

```
                             50
                             32

                    7.4             53
                    3.9             33

              4.3         4.2             55
              2.2         2.3             32

         5.1       0.83        4.4        73
         2.8       0.81        3.9        43
         2.0       0.51        2.6        35
         1.7       0.47        2.1        33
         7%        11%         6%         2%
```
Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air at a 10 m Ground Range (Megarad)
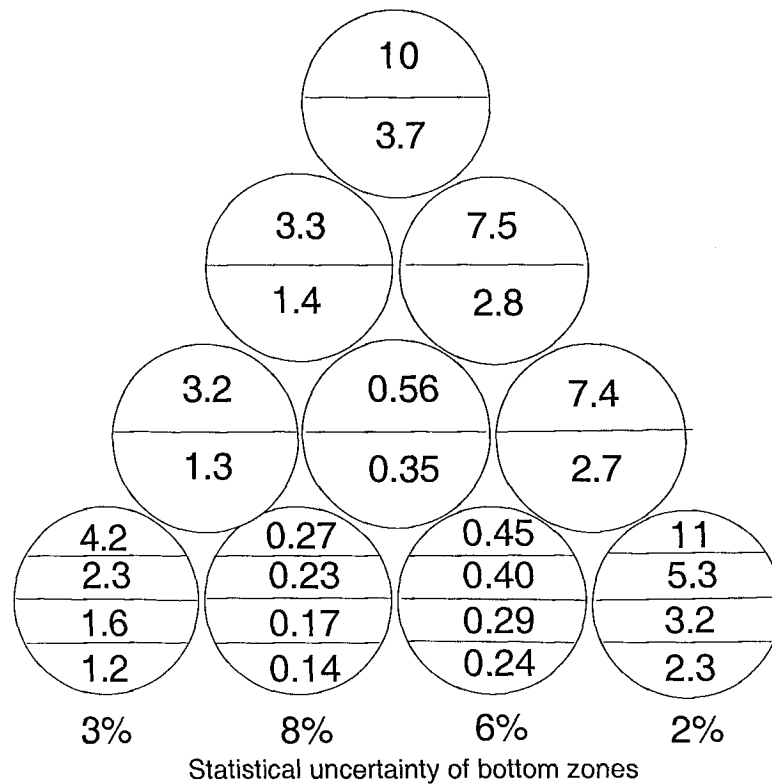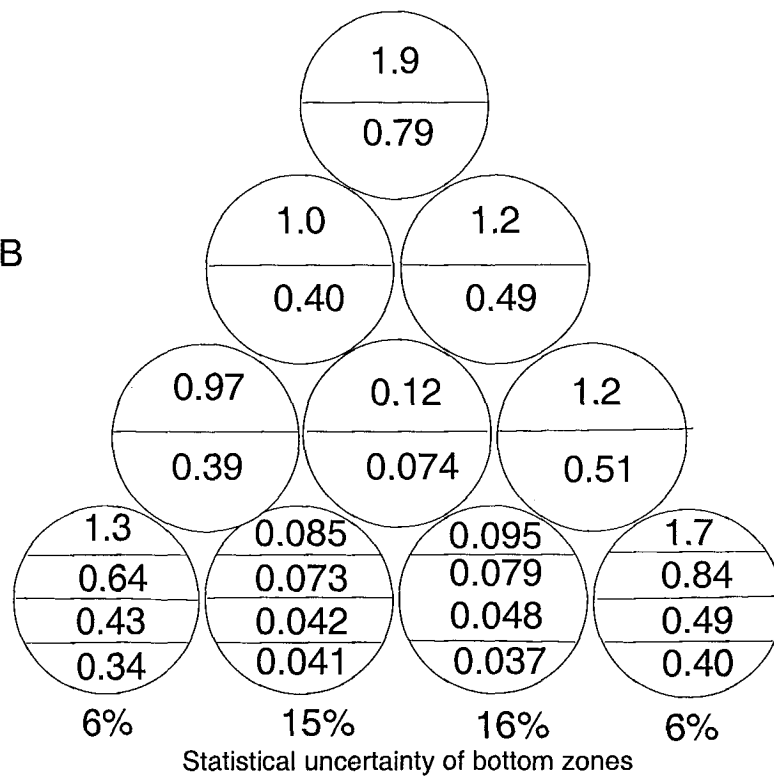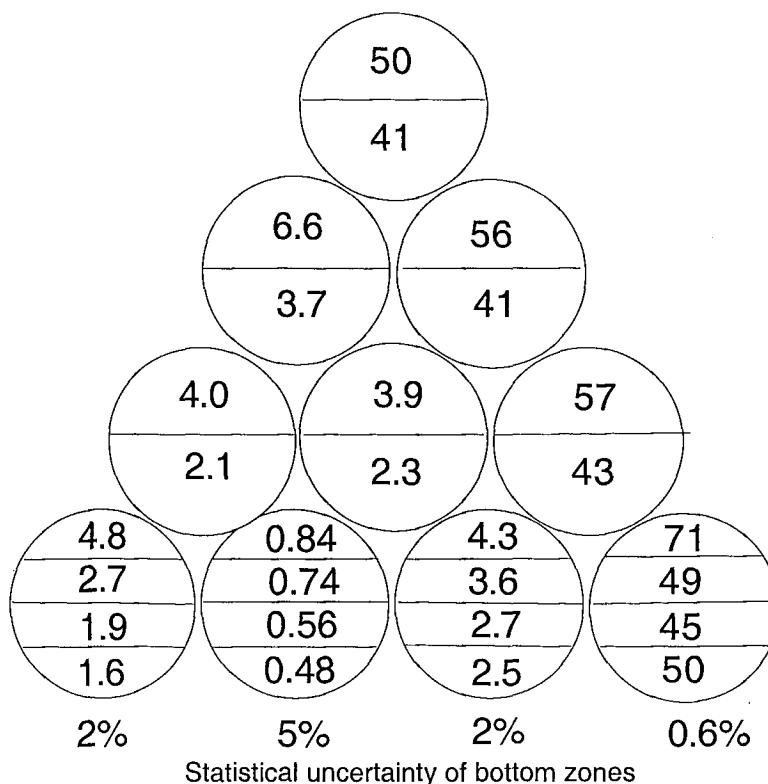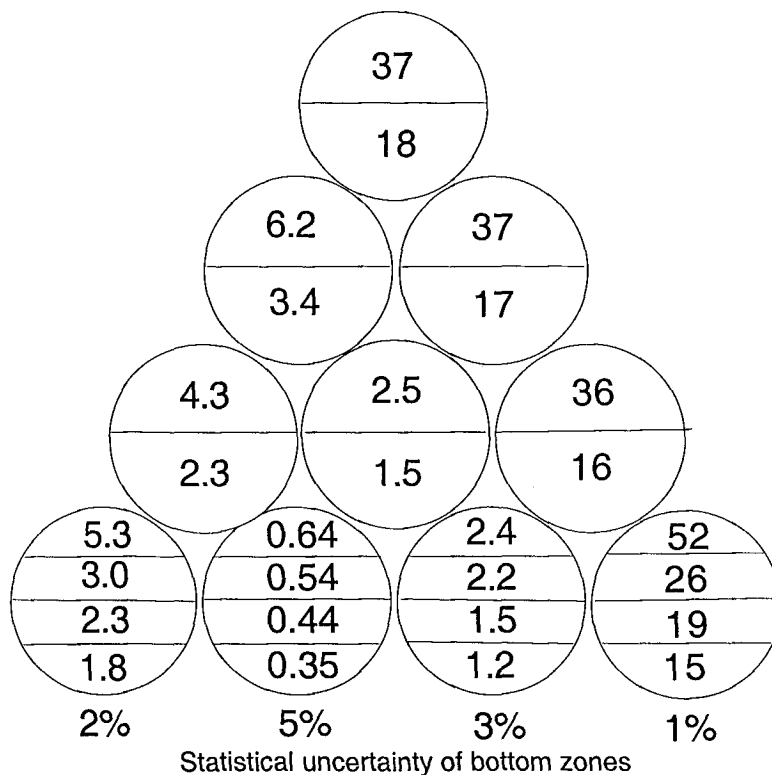
Yield: 10 kT   HOB: 10m

Fig. A3

14 Mev neutrons
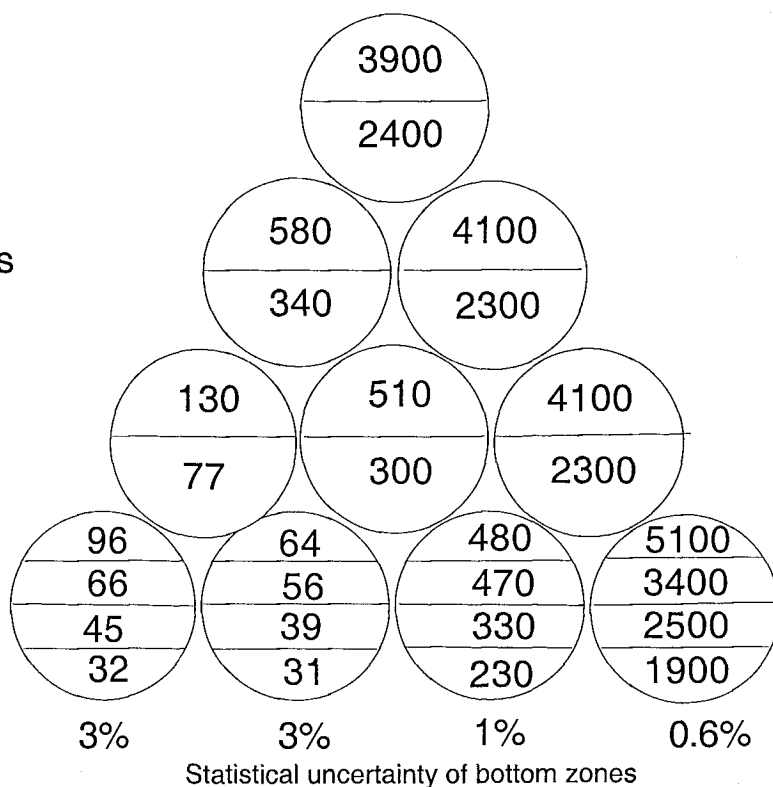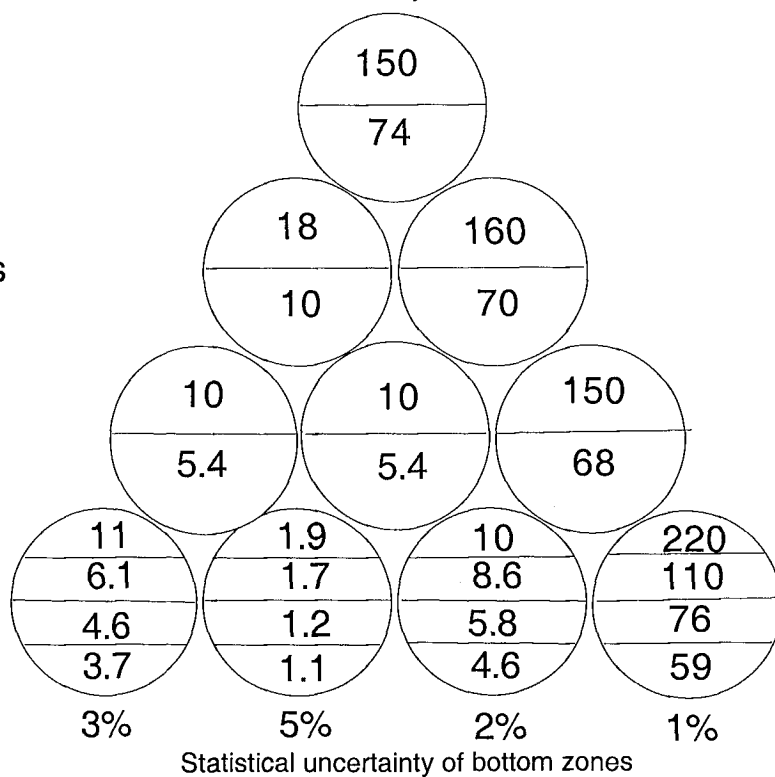
3900
2400

580 | 4100
340 | 2300

130 | 510 | 4100
77 | 300 | 2300

96 | 64 | 480 | 5100
66 | 56 | 470 | 3400
45 | 39 | 330 | 2500
32 | 31 | 230 | 1900

3%   3%   1%   0.6%

Statistical uncertainty of bottom zones

Fig. A4

Fission neutrons

150
74

18 | 160
10 | 70

10 | 10 | 150
5.4 | 5.4 | 68

11 | 1.9 | 10 | 220
6.1 | 1.7 | 8.6 | 110
4.6 | 1.2 | 5.8 | 76
3.7 | 1.1 | 4.6 | 59

3%   5%   2%   1%

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums on the Ground in Open Air underneath the Burst Point
(Megarad)

Yield: 10 kT   HOB: 10m

Fig. A1

14 Mev neutrons

11000
3900

5500   5800
1900   2000

4700   410   4900
1600   230   1600

5200	250	230	5100
3200	180	160	3400
1700	110	110	1800
870	96	66	960

8%   18%   14%   7%

Statistical uncertainty of bottom zones

Fig. A2

Fission neutrons

410
88

190   200
46   44

160   11   170
37   7.0   36

220	6.0	7.4	220
92	5.1	5.8	100
46	3.5	4.1	48
31	3.6	2.4	33

7%   21%   19%   7%

Statistical uncertainty of bottom zones

Appendix

**Detailed Agent Dose Distributions
Within Barrel and Container Stacks**

HOB Dependence of Lowest Radiation Dose in Double-Layer Running Stack
of 200-Liter Barrels in a Metal Roof Building at 20 m Ground Range from a 10 kT Burst
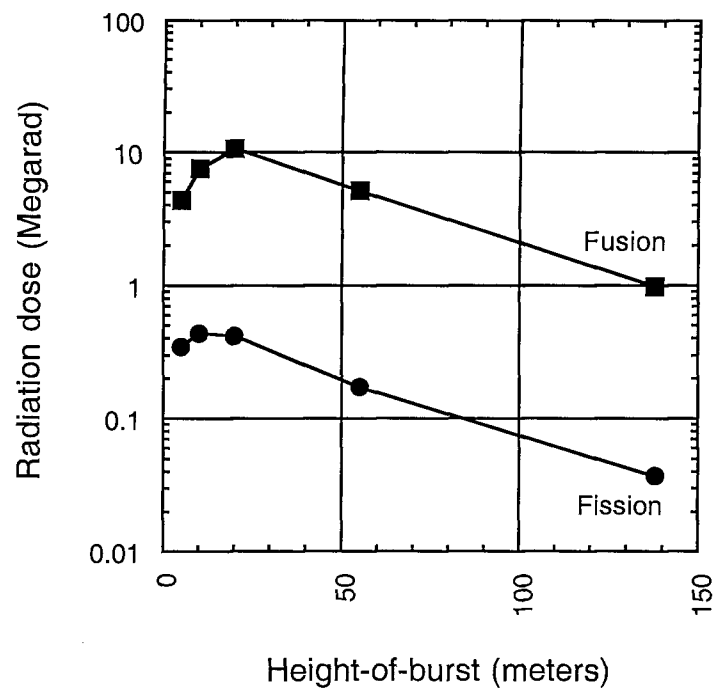
Fig. 33

Fractional Neutron Dose in 200-liter Drums inside a Metal Roof Building

10 m HOB
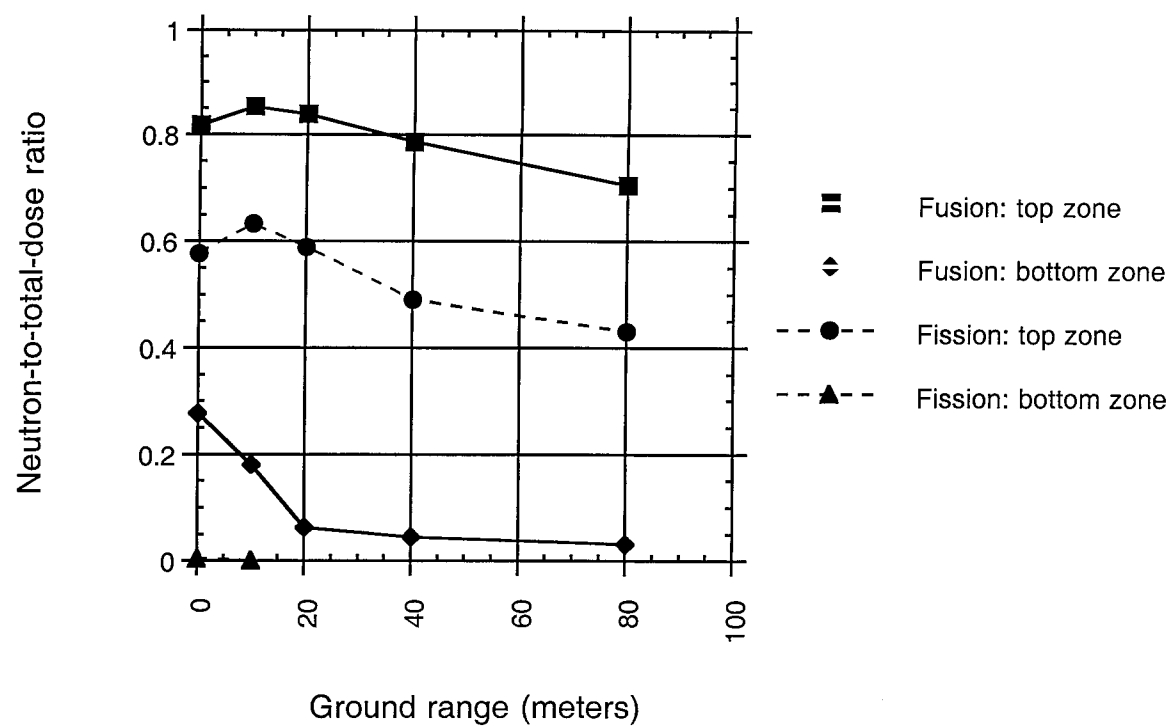
Fig.32

Fig. 31

Ground range (meters)

Lowest Radiation Dose in Double-Layer Running Stack of 200-Liter Barrels
in a Metal Roof Building from 10 kT at 10 m HOB
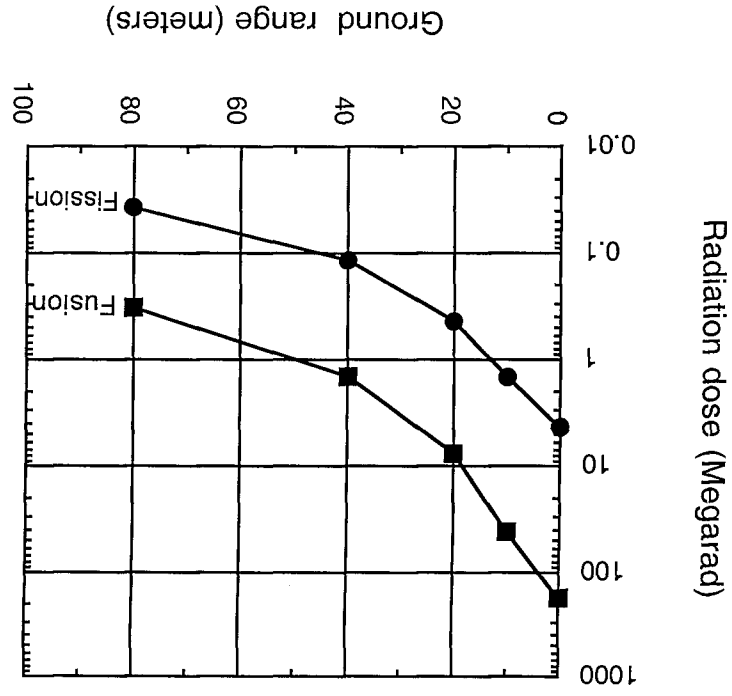
MCNP Code Geometry for Double-Layered Running Stack of Agent-filled 200 liter Barrels in a Storage Building

Detonation
at
HOB

20 cm thick
cylindrical
concrete
block wall

Air

4 m high
0.3 cm thick
steel roof

50 cm dia./0.2 cm Fe wall
toroidal barrels

Agent/barrel mixture

Soil
5 m thick, 1 km radius

R

R + 5 m
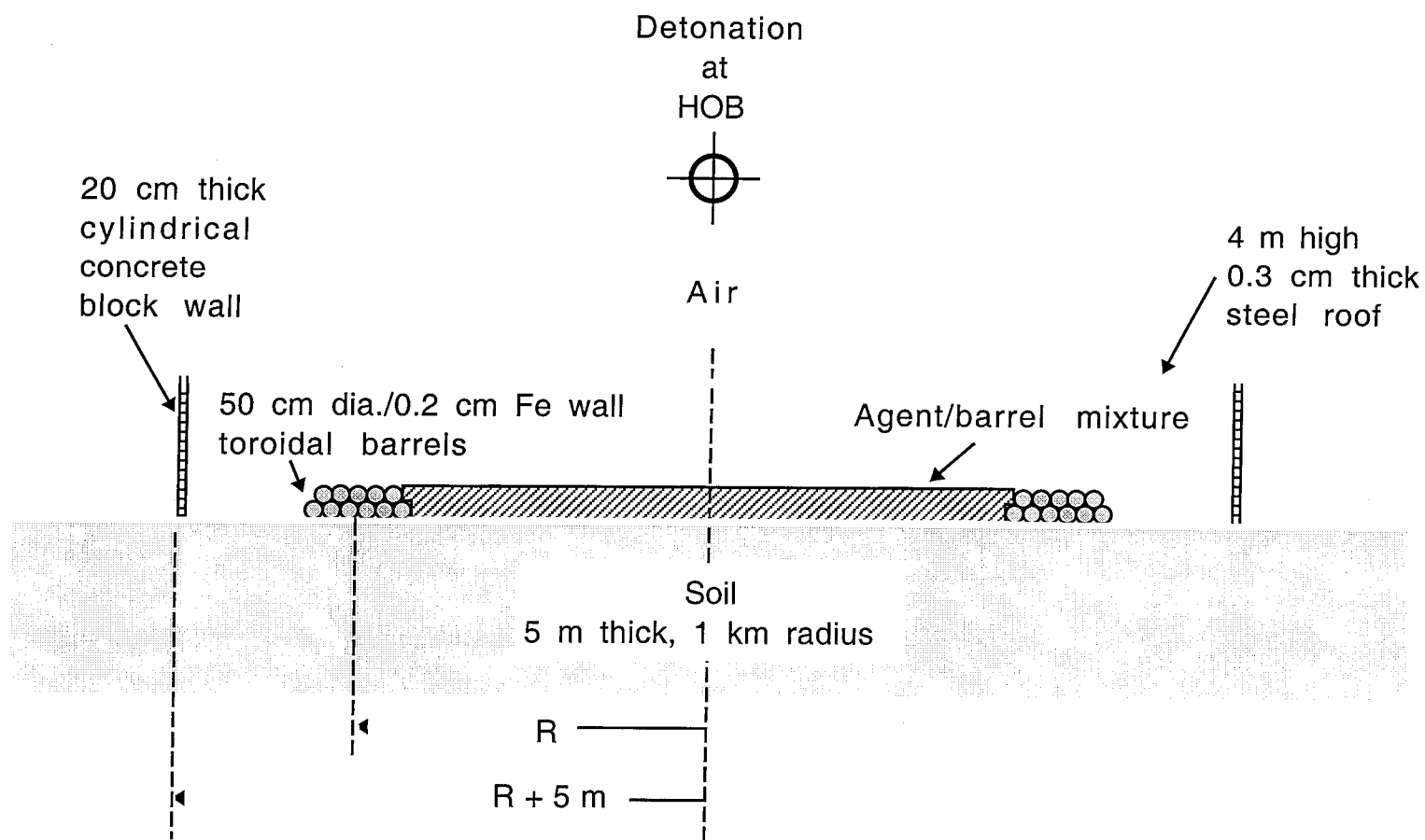
Fig. 30

Fractional Neutron Dose in a Double-Layer Running Stack of One-Ton Containers on the Ground in Open Air

10 m HOB

Legend:
- ■ Fusion: top zone
- ◆ Fusion: bottom zone
- ---●--- Fission: top zone

Fission bottom zone: Negligible neutron dose contribution

Y-axis: Neutron-to-total-dose ratio

X-axis: Ground range (meters)
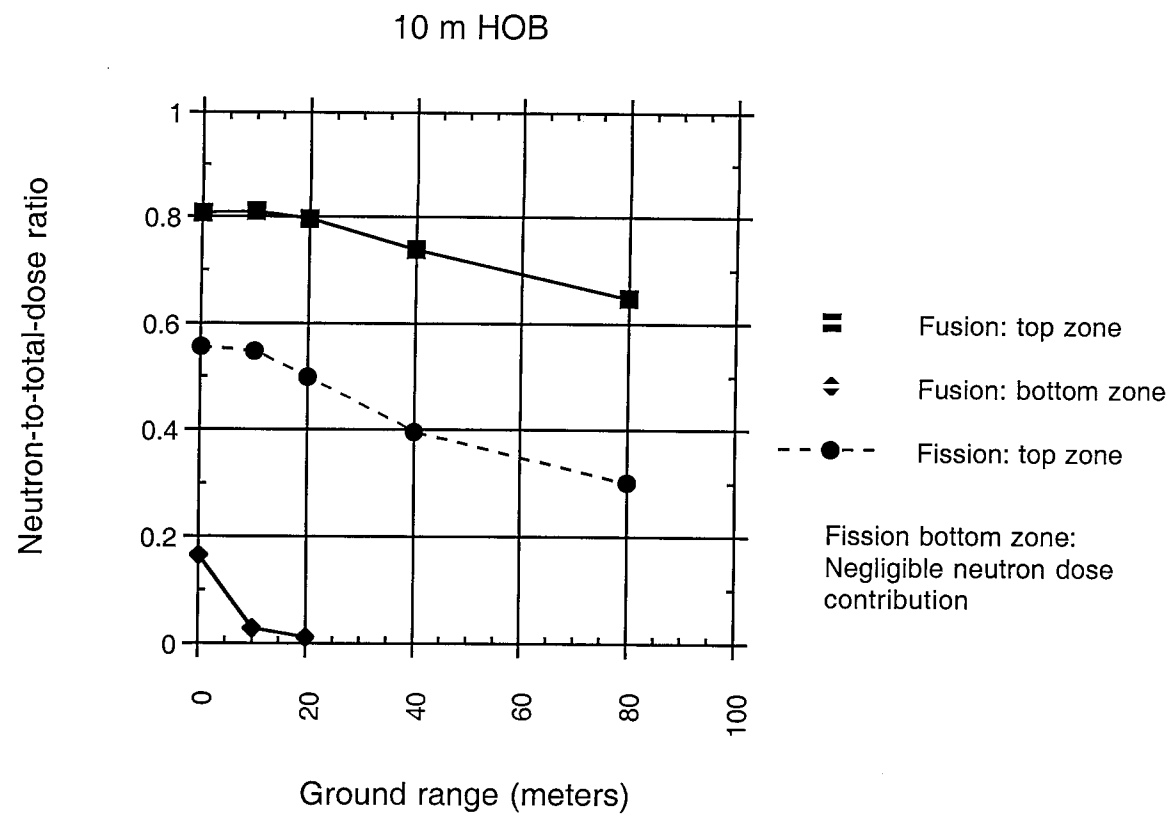
Fig. 29

Lowest Radiation Dose in Double-Layer Running Stack of One-Ton Agent Containers
from 10 kT Burst at 10 m HOB

Containers on the ground in open air or in a concrete block building
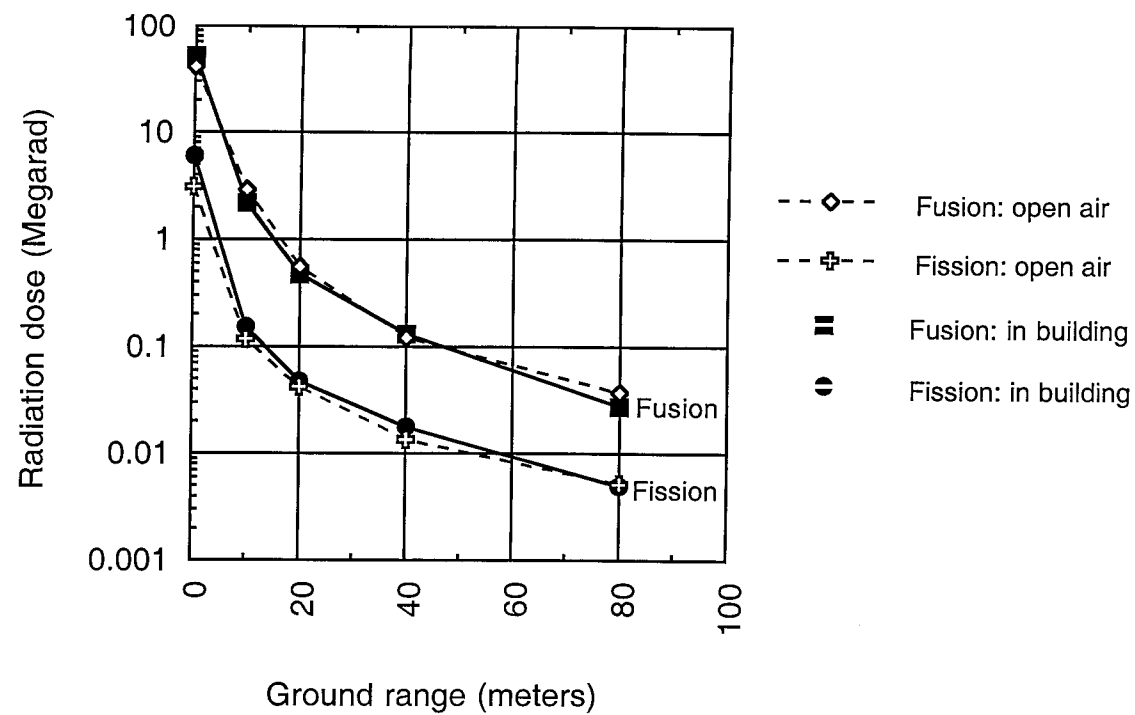
Fig. 28

Fractional Neutron Dose in a Single-Layer Running Stack of One-Ton Containers on the Ground in Open Air
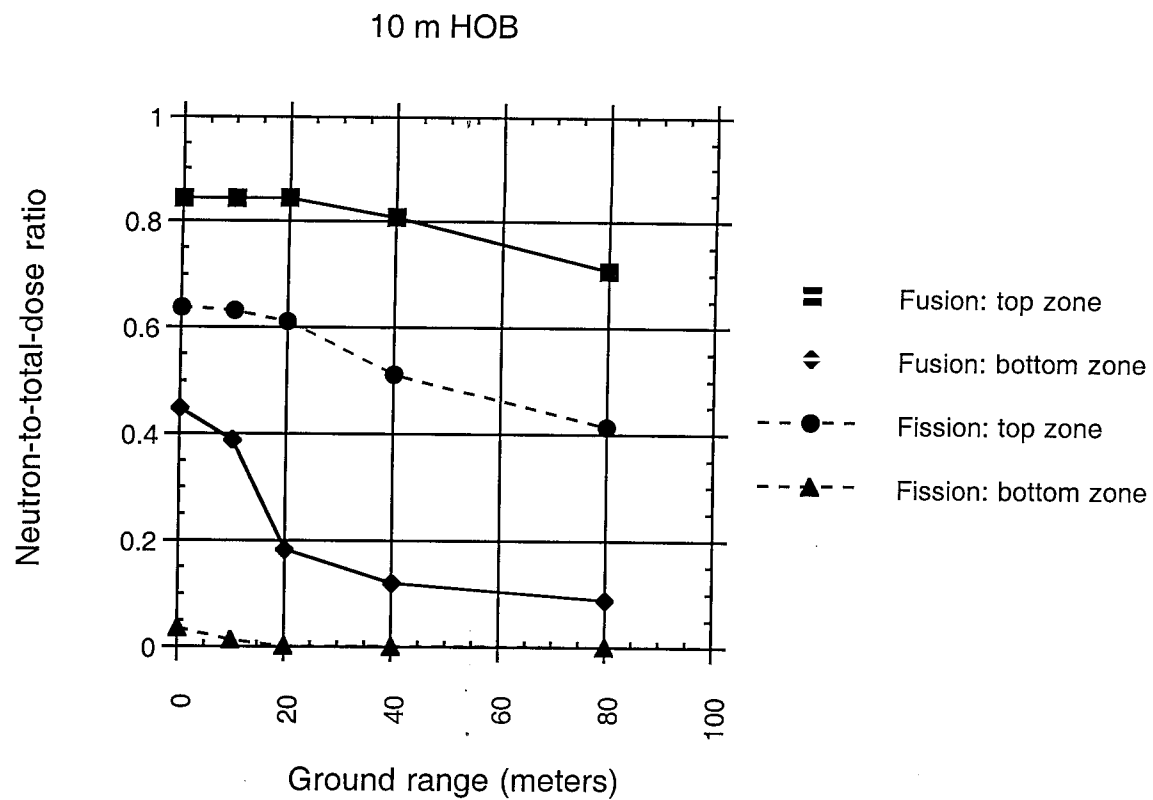
10 m HOB

Fig. 27

Lowest Radiation Dose in Single-Layer Running Stack of One-Ton Agent Containers from 10 kT at 10 m HOB

Containers on the ground in open air or in a concrete block building

Legend:
- - - ◇ - - Fusion: open air
- - - ✛ - - Fission: open air
▬ Fusion: in building
● Fission: in building
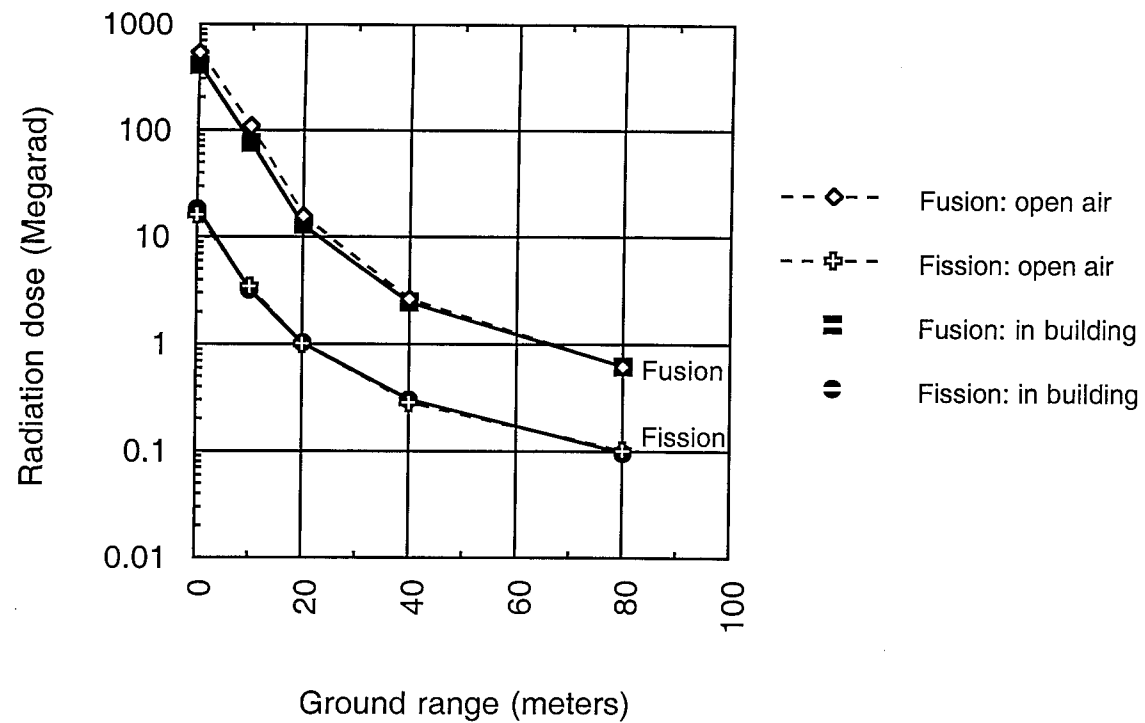
Fig. 26

MCNP Code Geometry for Double-Layered Running Stack of One-Ton Agent Containers in a Storage Building

Detonation
at
HOB

20 cm thick
cylindrical
concrete
block walls

4 m high
10 cm thick
concrete roof

80 cm dia.
1.5 cm Fe wall
toroidal containers

Air

Soil
5 m thick, 1 km radius

R - 5 m

R

R + 5 m

Note:
MCNP geometry for single-layered
running stack deletes upper layer
of five containers.
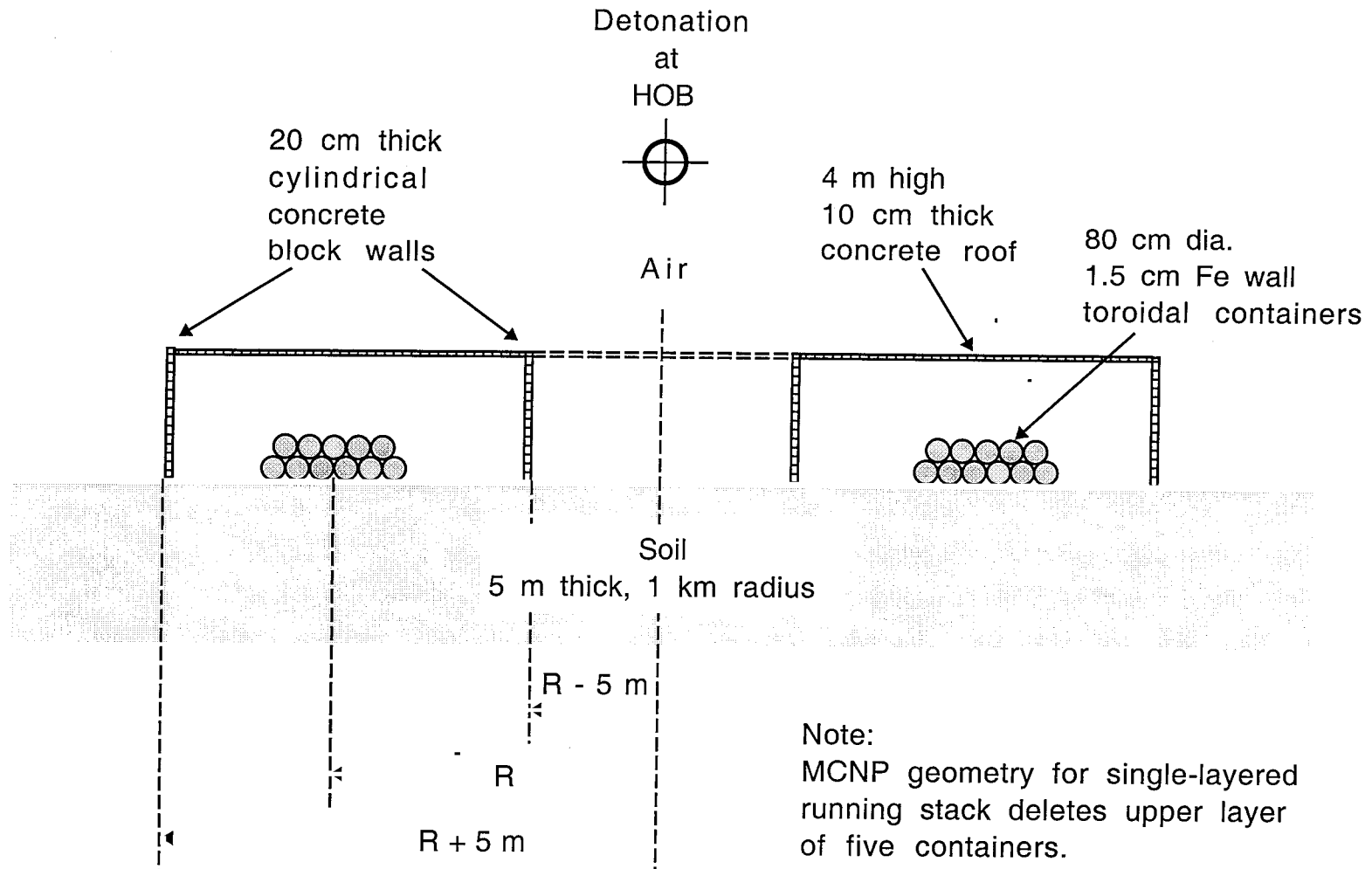
Fig. 25

Neutron Energy Dependence of Lowest Radiation Dose in Barrel Stack at a 10 m Ground Range from a Burst at 10 m HOB

Adjacent pyramids of ten 200 liter barrels on the ground in open air
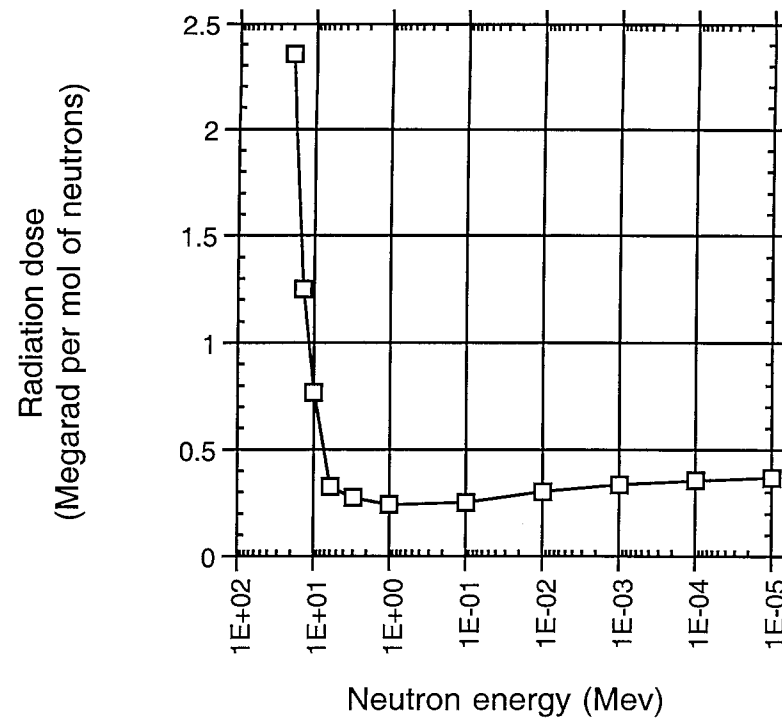
Fig. 24

Radiation Dose in 200-liter Drums inside a Concrete Block Building at a 20 m Ground Range
(Megarad)

Yield: 10 kT   **Neutron spectrum: Fission**

Fig. A43

2.5 m HOB
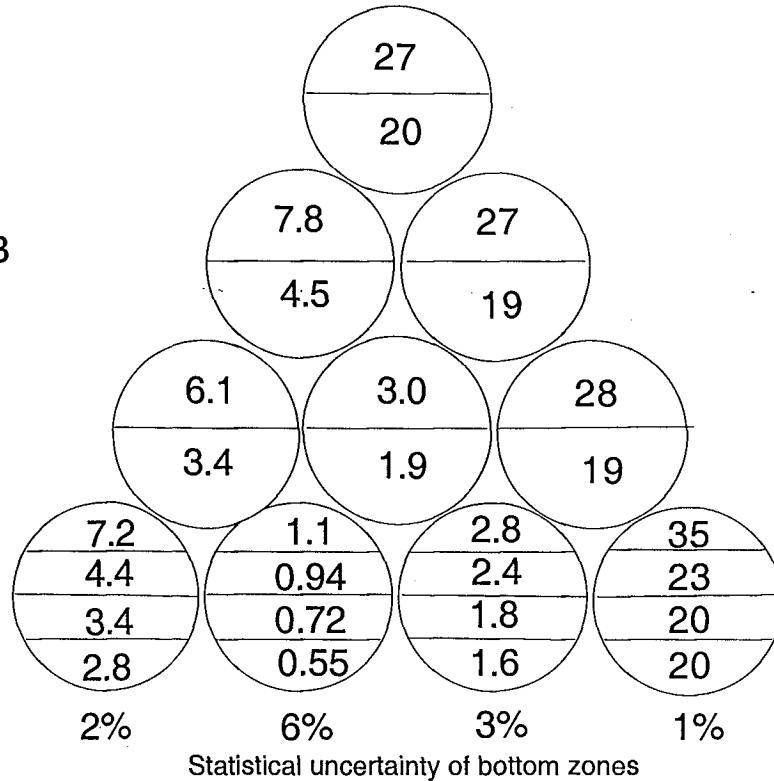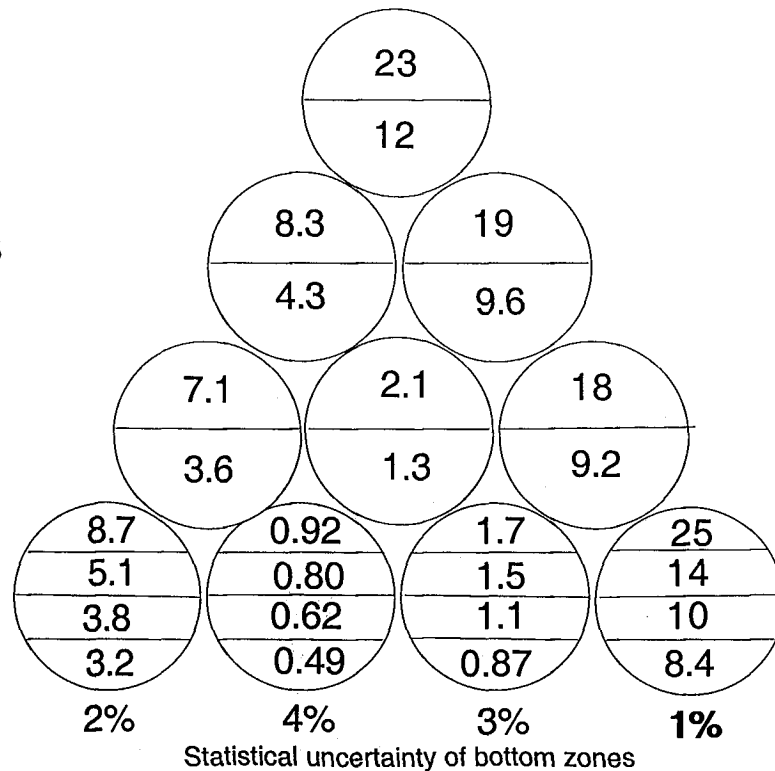
| 27 |
| 20 |

| 7.8 | | 27 |
| 4.5 | | 19 |

| 6.1 | 3.0 | 28 |
| 3.4 | 1.9 | 19 |

7.2	1.1	2.8	35
4.4	0.94	2.4	23
3.4	0.72	1.8	20
2.8	0.55	1.6	20

2%   6%   3%   1%

Statistical uncertainty of bottom zones

Fig. A44

20 m HOB

| 23 |
| 12 |

| 8.3 | | 19 |
| 4.3 | | 9.6 |

| 7.1 | 2.1 | 18 |
| 3.6 | 1.3 | 9.2 |

8.7	0.92	1.7	25
5.1	0.80	1.5	14
3.8	0.62	1.1	10
3.2	0.49	0.87	8.4

2%   4%   3%   **1%**

Statistical uncertainty of bottom zones

Radiation Dose in 200-liter Drums inside a Concrete Block Building at a 20 m Ground Range
(Megarad)

Yield: 10 kT   Neutron spectrum: Fission

Fig. A45

55 m HOB
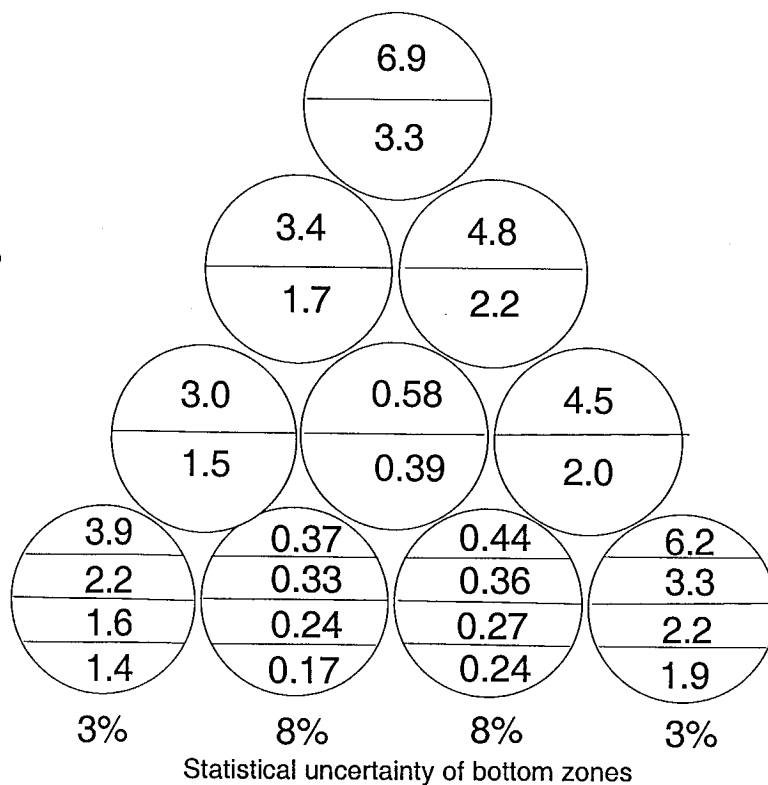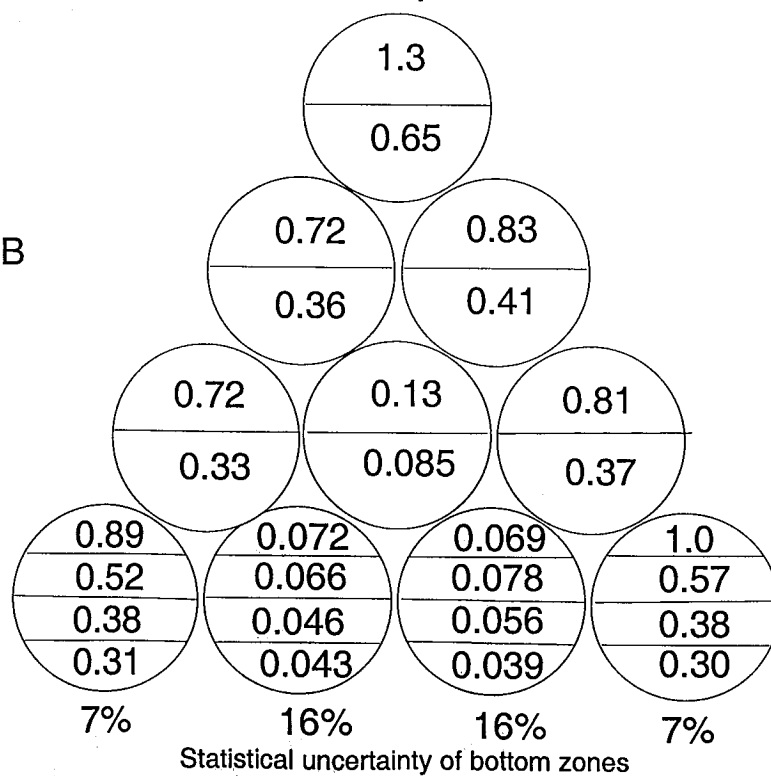
Statistical uncertainty of bottom zones

3%   8%   8%   3%

Fig. A46

138 m HOB

Statistical uncertainty of bottom zones

7%   16%   16%   7%

Radiation Dose in One-Ton Containers on the Ground in Open Air underneath the Burst Point
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons
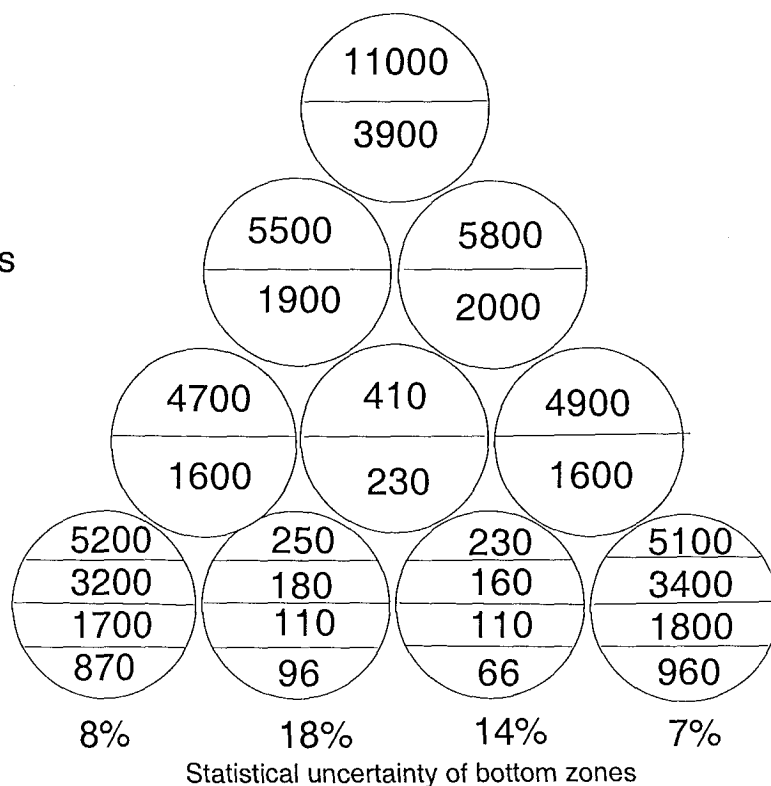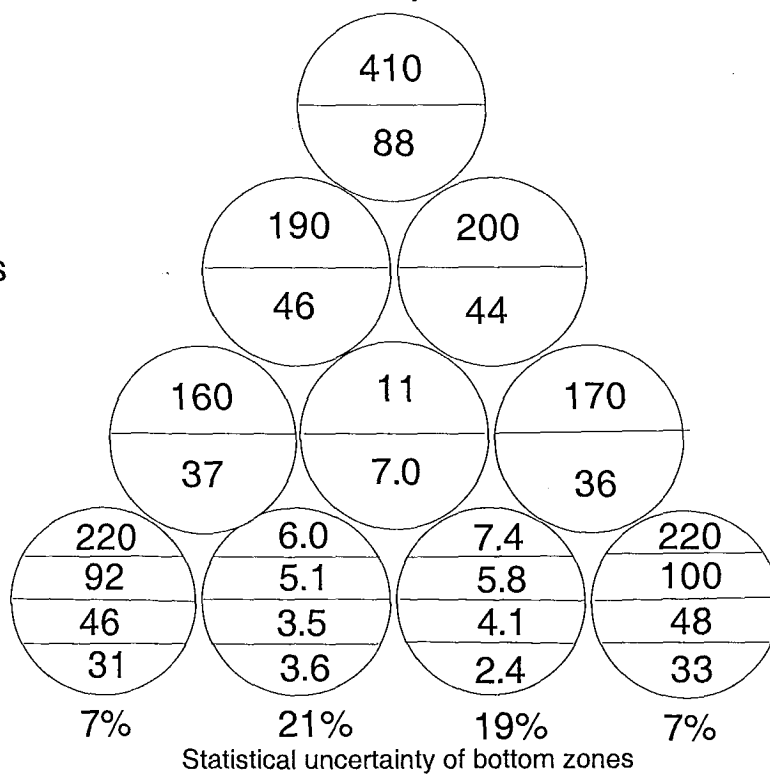
8600	8700	8900	9200	8800	8600
4300	4500	4600	4600	4600	4300
1600	1600	1700	1600	1600	1600
600	520	530	530	560	590
3%	3%	3%	3%	3%	3%

Statistical uncertainty of bottom zones

Fig. A47

Fission neutrons
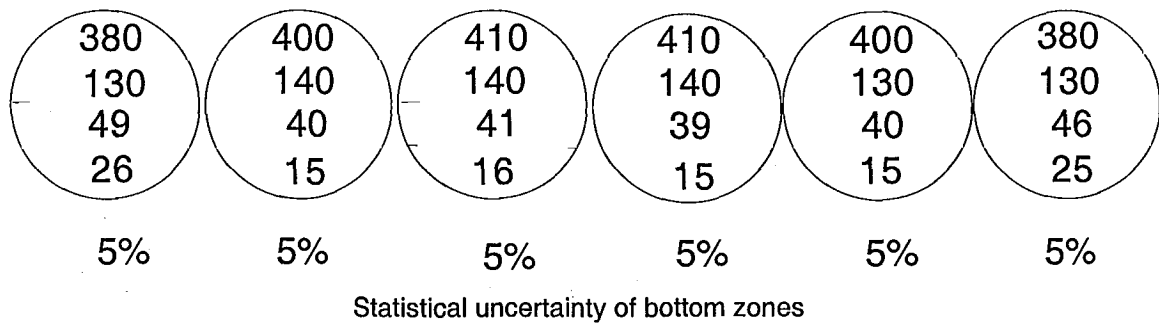
380	400	410	410	400	380
130	140	140	140	130	130
49	40	41	39	40	46
26	15	16	15	15	25
5%	5%	5%	5%	5%	5%

Statistical uncertainty of bottom zones

Fig. A48

Radiation Dose in One-Ton Containers on the Ground in Open Air
at a 10 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

2600	2900	3200	3600	4000	4500
1100	1300	1400	1700	1900	2500
250	300	350	430	520	1500
86	92	110	140	170	860
2%	2%	2%	1%	1%	0.7%

Statistical uncertainty of bottom zones

Fig. A49

Fission neutrons
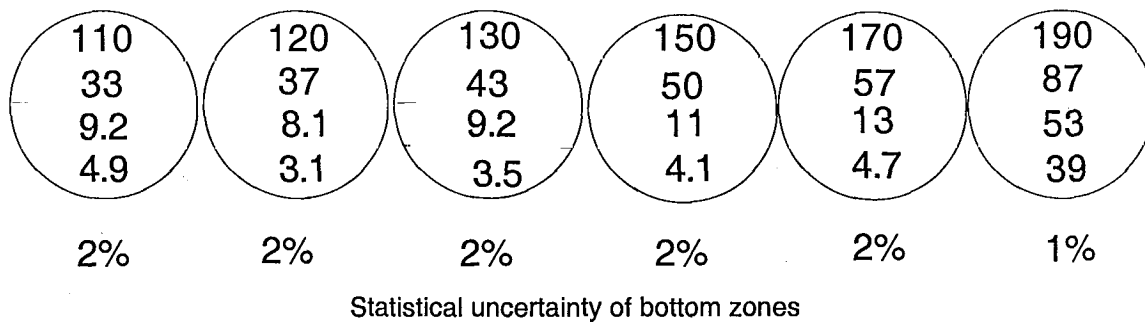
110	120	130	150	170	190
33	37	43	50	57	87
9.2	8.1	9.2	11	13	53
4.9	3.1	3.5	4.1	4.7	39
2%	2%	2%	2%	2%	1%

Statistical uncertainty of bottom zones

Fig. A50

Radiation Dose in One-Ton Containers on the Ground in Open Air at a 20 m Ground Range (Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

820	900	980	1100	1200	1400
190	210	240	280	320	870
42	41	46	53	65	670
18	14	16	18	27	560
1%	1%	1%	1%	1%	0.4%

Statistical uncertainty of bottom zones

Fig. A51

Fission neutrons

34	37	40	44	48	58
7.8	8.1	9.0	9.7	11	34
3.1	2.1	2.4	2.5	3.0	26
1.9	0.90	1.0	1.0	1.3	23
2%	2%	2%	2%	2%	0.7%

Statistical uncertainty of bottom zones

Fig. A52

Radiation Dose in One-Ton Containers on the Ground in Open Air
at a 40m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

150	160	170	180	200	310
26	26	28	29	33	220
8.9	6.5	7.0	7.5	10	190
4.6	2.5	2.7	3.0	6.3	200
3%	3%	3%	3%	3%	0.7%

Statistical uncertainty of bottom zones

Fig. A53

Fission neutrons

8.2	8.6	8.9	9.3	9.8	14
2.4	2.2	2.3	2.3	2.5	9.2
1.2	0.66	0.68	0.70	0.80	7.7
0.84	0.29	0.28	0.29	0.38	7.8
2%	3%	3%	3%	3%	0.7%

Statistical uncertainty of bottom zones

Fig. A54

Radiation Dose in One-Ton Containers on the Ground in Open Air at a 80m Ground Range (Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

22	22	23	23	24	68
6.1	5.7	5.9	5.9	6.3	49
2.5	1.6	1.6	1.7	2.1	44
1.5	0.59	0.62	0.63	1.4	47
3%	4%	4%	4%	4%	1%

Statistical uncertainty of bottom zones

Fig. A55

Fission neutrons

2.2	2.2	2.3	2.3	2.4	3.5
0.81	0.71	0.73	0.74	0.77	2.3
0.45	0.22	0.23	0.23	0.25	1.9
0.32	0.087	0.10	0.093	0.12	1.9
3%	4%	4%	4%	4%	1%

Statistical uncertainty of bottom zones

Fig. A56

Radiation Dose in One-Ton Containers inside a Concrete Block Building underneath the Burst Point
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

6400	6900	7000	7100	6800	6600
3200	3400	3400	3400	3300	3200
1200	1200	1200	1200	1200	1300
530	410	400	410	410	550
3%	4%	4%	4%	4%	3%

Statistical uncertainty of bottom zones

Fig. A57

Fission neutrons

300	320	320	310	300	300
120	120	120	120	120	120
57	39	40	38	36	56
36	20	18	19	16	39
4%	5%	5%	5%	5%	4%
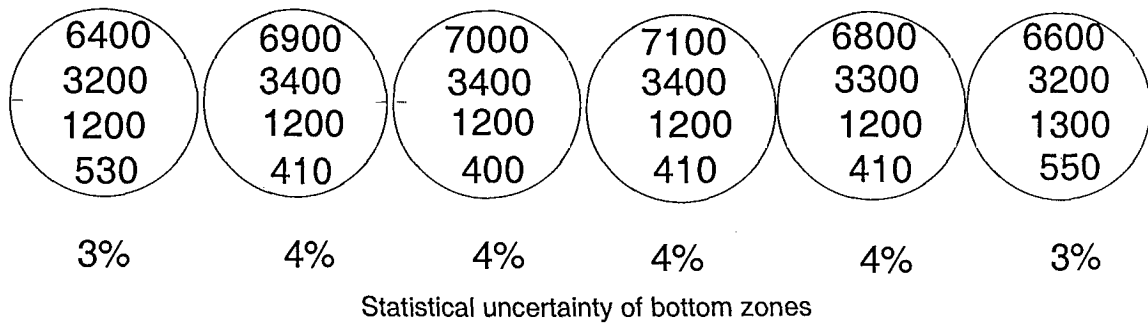
Statistical uncertainty of bottom zones
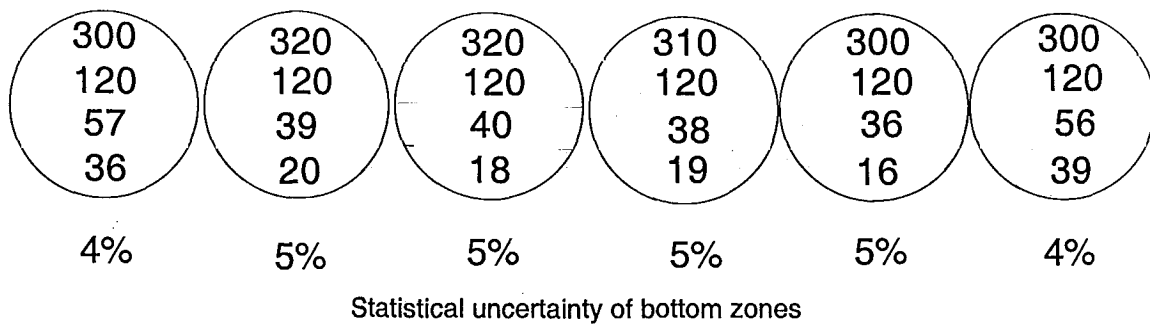
Fig. A58

Radiation Dose in One-Ton Containers inside a Concrete Block Building at a 10 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

1600	1800	2000	2300	2600	2700
640	740	860	1000	1200	1200
190	190	230	280	330	660
89	63	76	96	120	410
2%	2%	2%	2%	2%	1%

Statistical uncertainty of bottom zones

Fig. A59

Fission neutrons
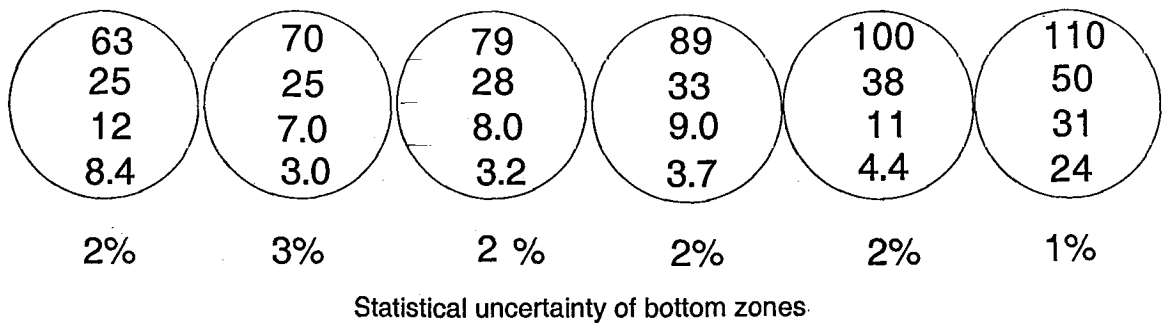
63	70	79	89	100	110
25	25	28	33	38	50
12	7.0	8.0	9.0	11	31
8.4	3.0	3.2	3.7	4.4	24
2%	3%	2 %	2%	2%	1%

Statistical uncertainty of bottom zones

Fig. A60

Radiation Dose in One-Ton Containers inside a Concrete Block Building at a 20 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

430	470	510	560	610	750
130	140	150	170	190	460
41	32	36	39	48	330
22	12	13	15	20	280
2%	2%	2%	2%	2%	1%

Statistical uncertainty of bottom zones

Fig. A61

Fission neutrons

18	20	22	23	25	32
7.4	7.0	7.3	7.8	8.9	19
4.0	2.2	2.3	2.5	2.8	13
2.9	0.96	1.0	1.1	1.2	11
3%	4%	4%	4%	4%	2%
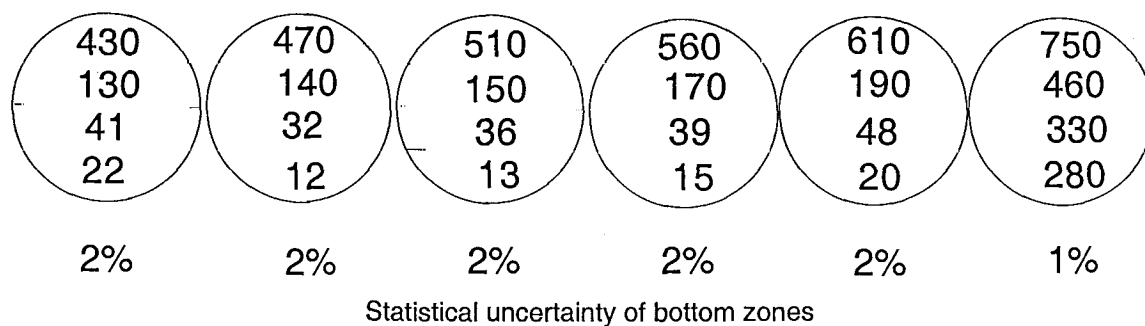
Statistical uncertainty of bottom zones
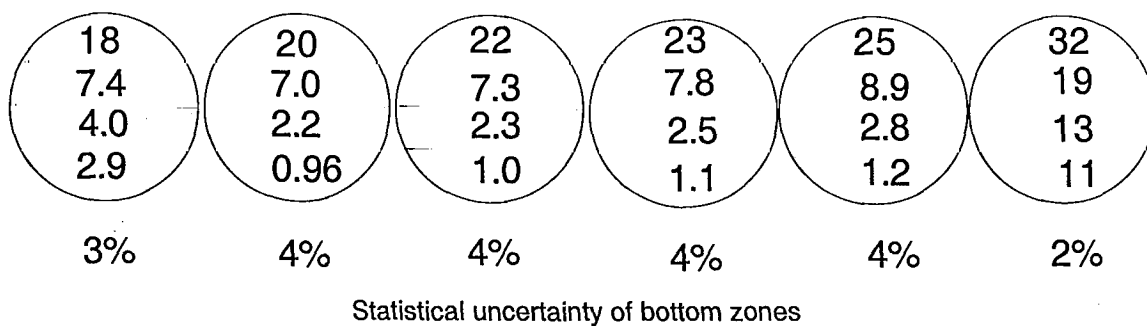
Fig. A62

Radiation Dose in One-Ton Containers inside a Concrete Block Building at a 40 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

87	94	100	110	120	170
23	22	24	25	30	120
9.4	6.0	6.4	6.6	8.7	96
5.8	2.4	2.5	2.6	4.4	92
2%	3%	3%	3%	2%	1%

Statistical uncertainty of bottom zones

Fig. A63

Fission neutrons
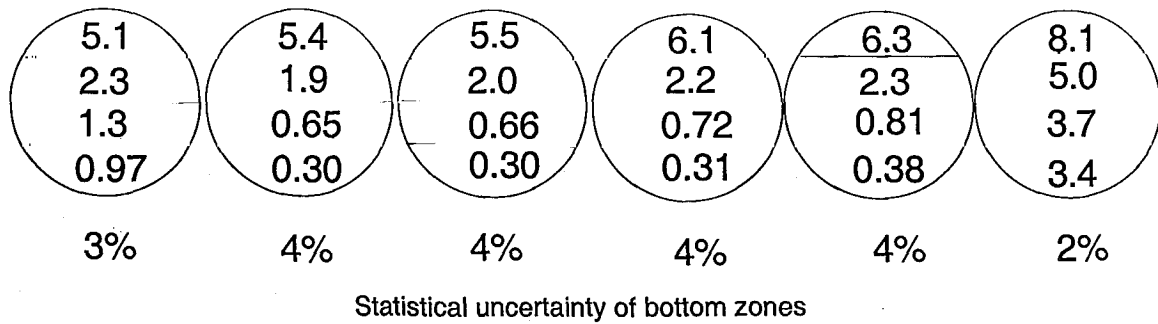
5.1	5.4	5.5	6.1	6.3	8.1
2.3	1.9	2.0	2.2	2.3	5.0
1.3	0.65	0.66	0.72	0.81	3.7
0.97	0.30	0.30	0.31	0.38	3.4
3%	4%	4%	4%	4%	2%

Statistical uncertainty of bottom zones

Fig. A64

Radiation Dose in One-Ton Containers inside a Concrete Block Building at a 80m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

17.3	18	19	20	21	37
5.5	5.1	5.2	5.4	6.2	25
2.5	1.5	1.5	1.6	2.0	21
1.6	0.60	0.62	0.59	1.0	21
3%	4%	4%	4%	4%	2%

Statistical uncertainty of bottom zones

Fig. A65

Fission neutrons

1.5	1.5	1.5	1.6	1.7	2.1
0.71	0.59	0.61	0.62	0.67	1.2
0.43	0.21	0.21	0.22	0.23	0.93
0.33	0.089	0.097	0.097	0.11	0.81
3%	4%	4%	4%	4%	2%

Statistical uncertainty of bottom zones

Fig. A66

Radiation Dose in One-Ton Containers on the Ground in Open Air underneath the Burst Point
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

6900 / 1400	7200 / 1400	7300 / 1400	7300 / 1400	6900 / 1300
2700 / 1400 / 530 / 230	400 / 130 / 60 / 29	480 / 140 / 54 / 41	470 / 150 / 67 / 35	410 / 140 / 64 / 41	2700 / 1400 / 490 / 230

5%   11%   11%   10%   10%   5%

Statistical uncertainty of bottom zones

Fig. A67

Fission neutrons
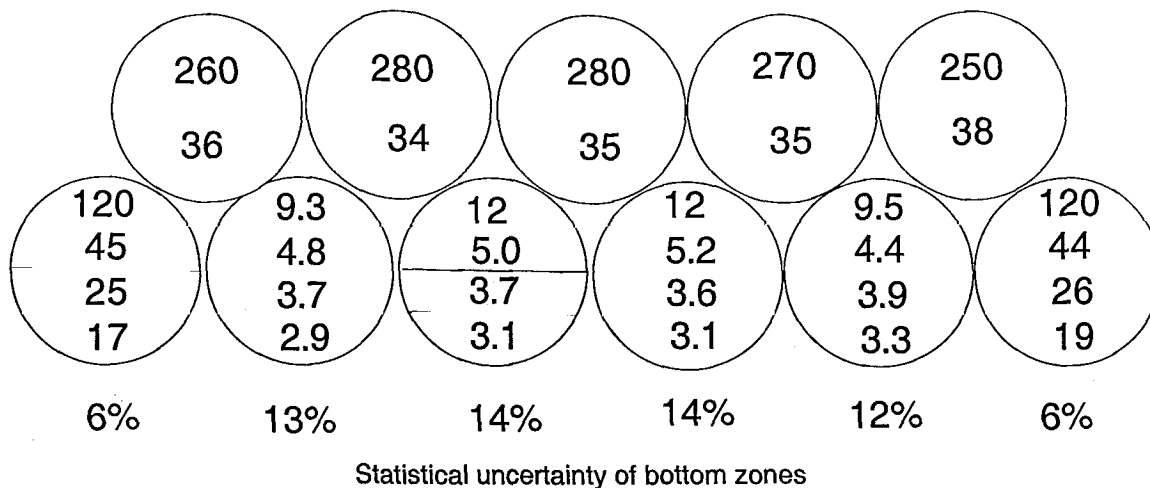
260 / 36	280 / 34	280 / 35	270 / 35	250 / 38
120 / 45 / 25 / 17	9.3 / 4.8 / 3.7 / 2.9	12 / 5.0 / 3.7 / 3.1	12 / 5.2 / 3.6 / 3.1	9.5 / 4.4 / 3.9 / 3.3	120 / 44 / 26 / 19

6%   13%   14%   14%   12%   6%

Statistical uncertainty of bottom zones

Fig. A68

Radiation Dose in One-Ton Containers on the Ground in Open Air at a 10 m Ground Range
(Megarad)

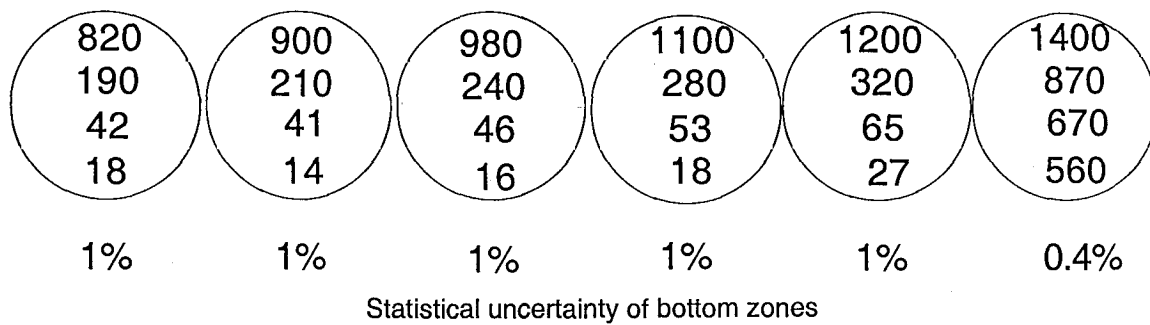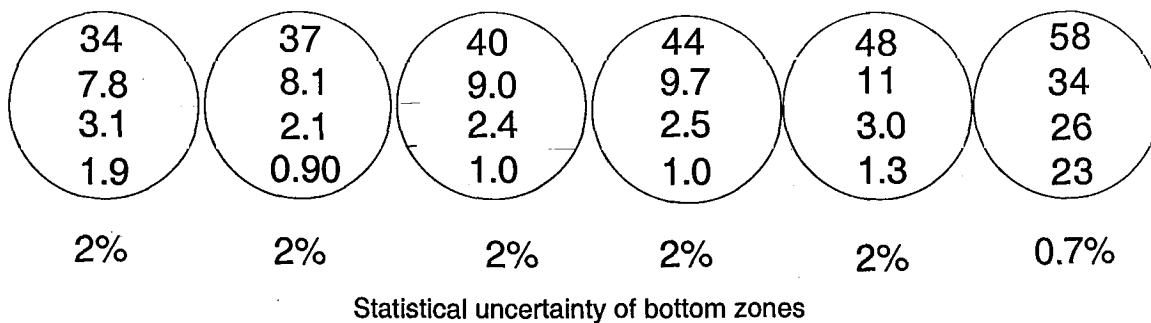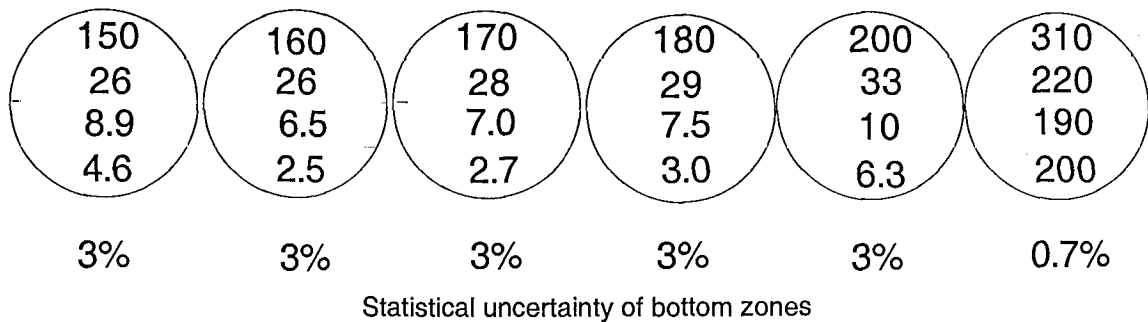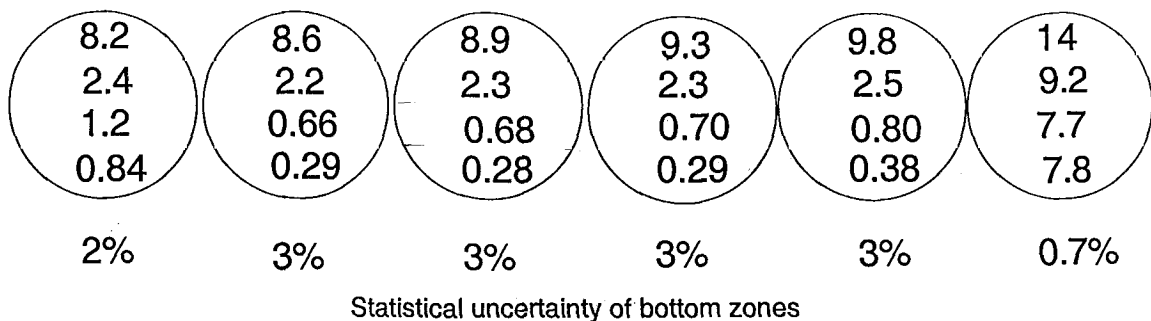Yield: 10 kT   HOB: 10m

14 Mev neutrons

1800	2000	2300	2600	3300
200	230	280	350	1300

68	29	35	43	96	4600
38	12	14	18	82	2400
24	5.2	5.7	7.4	44	1400
15	2.7	2.9	3.8	24	850

2%	4%	4%	4%	2%	0.5%

Statistical uncertainty of bottom zones

Fig. A69

Fission neutrons
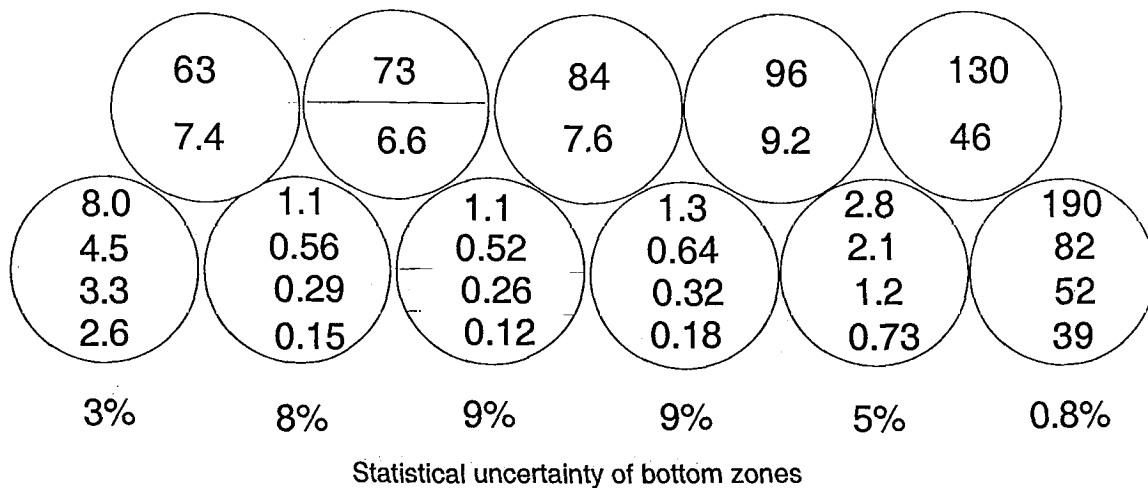
63	73	84	96	130
7.4	6.6	7.6	9.2	46

8.0	1.1	1.1	1.3	2.8	190
4.5	0.56	0.52	0.64	2.1	82
3.3	0.29	0.26	0.32	1.2	52
2.6	0.15	0.12	0.18	0.73	39

3%	8%	9%	9%	5%	0.8%

Statistical uncertainty of bottom zones

Fig. A70

Radiation Dose in One-Ton Containers on the Ground in Open Air
at a 20 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons
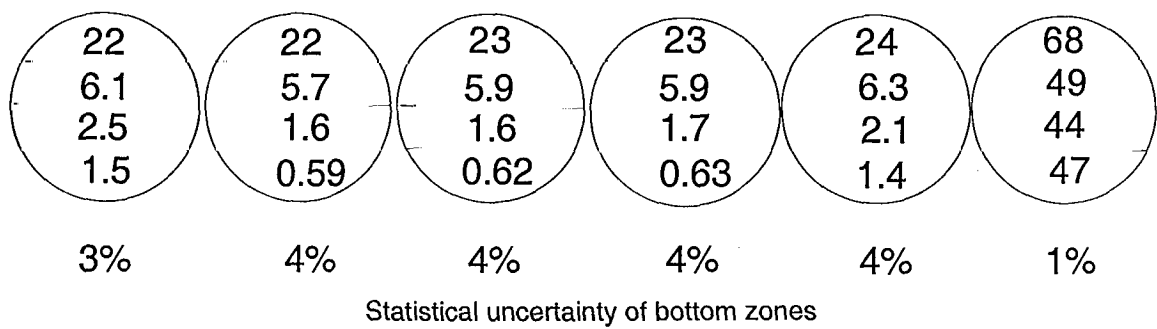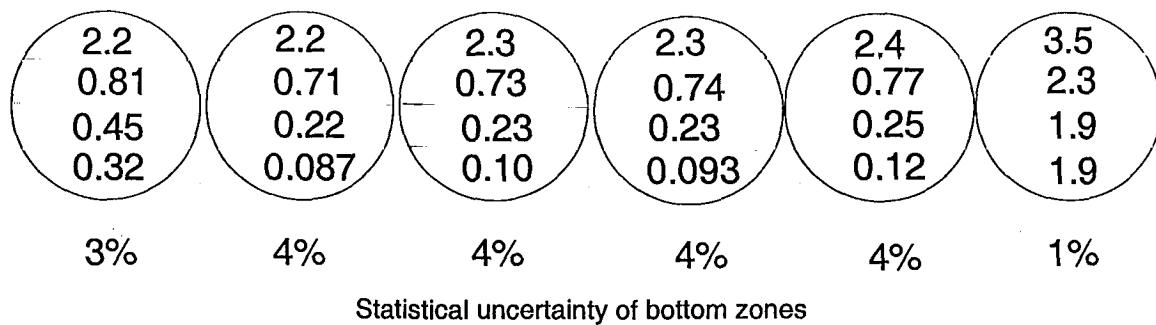
420	470	520	580	1000
32	30	34	42	62

26	5.2	5.3	6.1	42	1400
14	2.3	2.3	2.9	47	880
8.8	1.1	1.0	1.5	18	680
5.9	0.61	0.55	0.97	12	560

3%	6%	6%	6%	2%	0.4%

Statistical uncertainty of bottom zones

Fig. A71

Fission neutrons
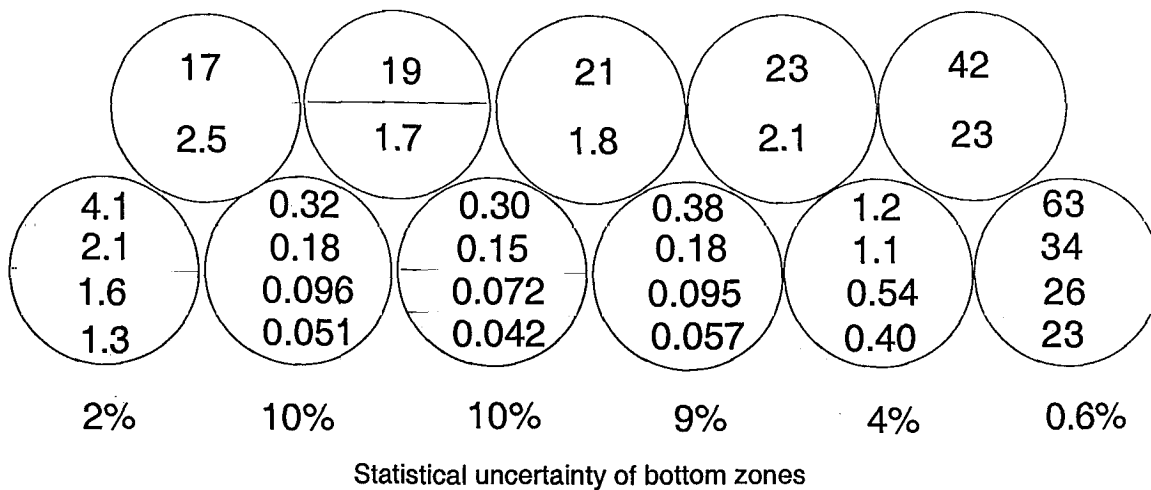
17	19	21	23	42
2.5	1.7	1.8	2.1	23

4.1	0.32	0.30	0.38	1.2	63
2.1	0.18	0.15	0.18	1.1	34
1.6	0.096	0.072	0.095	0.54	26
1.3	0.051	0.042	0.057	0.40	23

2%	10%	10%	9%	4%	0.6%

Statistical uncertainty of bottom zones

Fig. A72

Radiation Dose in One-Ton Containers on the Ground in Open Air
at a 40 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

71	74	79	84	240
6.7	5.0	5.3	6.6	180

10	0.88	0.91	1.1	9.9	320
5.3	0.48	0.42	0.54	7.5	220
3.6	0.24	0.22	0.31	4.0	190
2.6	0.13	0.12	0.21	3.8	200

3%	9%	9%	8%	3%	0.6%

Statistical uncertainty of bottom zones

Fig. A73

Fission neutrons
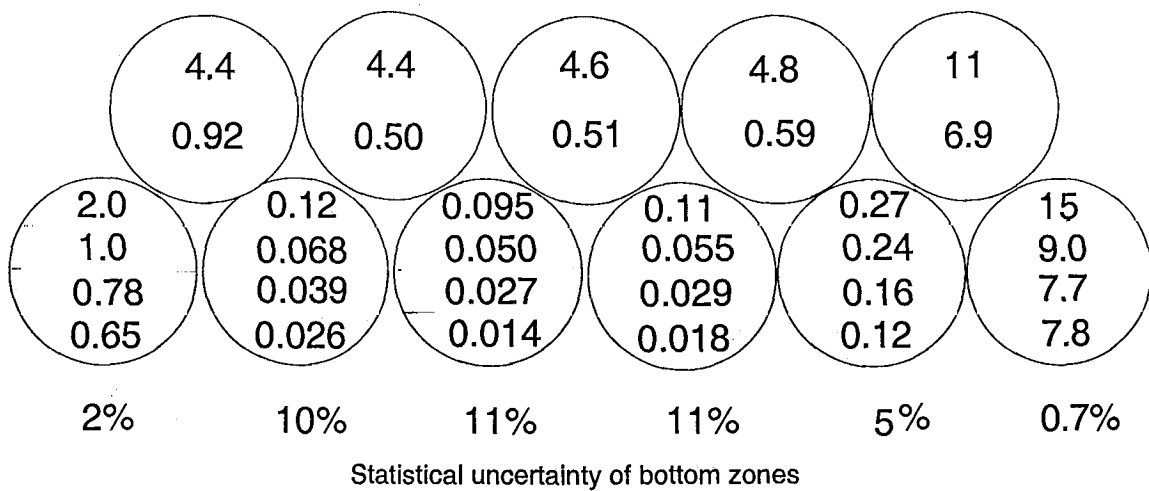
4.4	4.4	4.6	4.8	11
0.92	0.50	0.51	0.59	6.9

2.0	0.12	0.095	0.11	0.27	15
1.0	0.068	0.050	0.055	0.24	9.0
0.78	0.039	0.027	0.029	0.16	7.7
0.65	0.026	0.014	0.018	0.12	7.8

2%	10%	11%	11%	5%	0.7%

Statistical uncertainty of bottom zones

Fig. A74

Radiation Dose in One-Ton Containers on the Ground in Open Air at a 80 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

	14	14	14	15	54
	2.0	1.3	1.3	1.6	40

4.1	0.24	0.26	0.25	1.8	67
2.1	0.14	0.12	0.14	1.4	48
1.4	0.068	0.065	0.069	0.87	43
1.1	0.042	0.037	0.050	0.95	46

4%	15%	16%	16%	5%	1%

Statistical uncertainty of bottom zones

Fig. A75

Fission neutrons
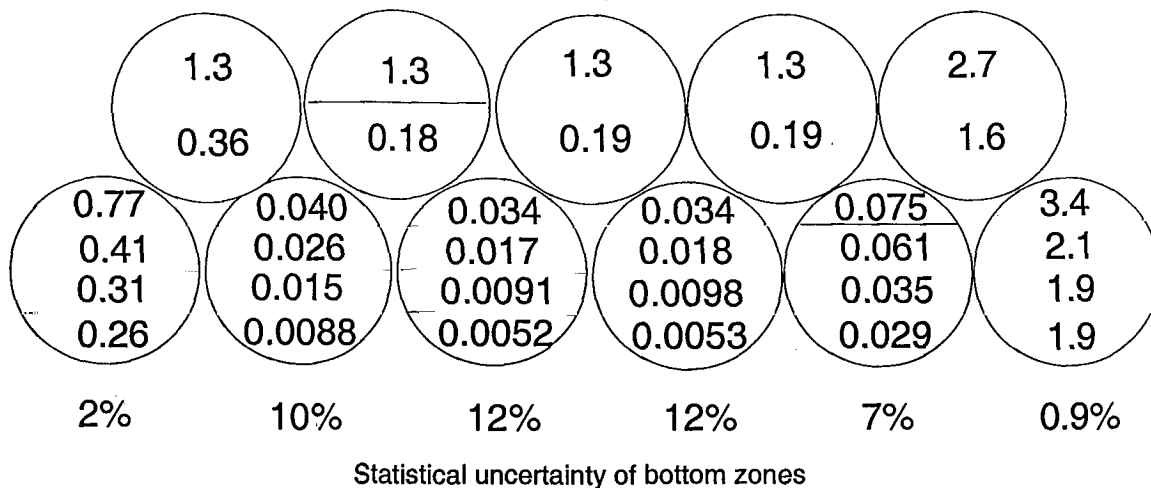
	1.3	1.3	1.3	1.3	2.7
	0.36	0.18	0.19	0.19	1.6

0.77	0.040	0.034	0.034	0.075	3.4
0.41	0.026	0.017	0.018	0.061	2.1
0.31	0.015	0.0091	0.0098	0.035	1.9
0.26	0.0088	0.0052	0.0053	0.029	1.9

2%	10%	12%	12%	7%	0.9%

Statistical uncertainty of bottom zones

Fig. A76

Radiation Dose in One-Ton Containers inside a Concrete Block Building underneath the Burst Point
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

5200	5400	5400	5500	5200
1100	1000	1000	1000	1100

2200	300	310	330	280	2300
1100	120	110	120	110	1200
490	69	66	65	62	510
290	50	52	41	48	310

4%   8%   8%   9%   9%   4%

Statistical uncertainty of bottom zones

Fig. A77

Fission neutrons

210	210	210	210	210
48	30	31	31	49

130	11	11	10	10	120
58	8.0	7.4	6.8	7.4	56
38	7.6	5.9	5.9	6.0	39
29	7.3	6.1	6.3	6.0	33

4%   11%   11%   9%   10%   5%

Statistical uncertainty of bottom zones

Fig. A78

Radiation Dose in One-Ton Containers inside a Concrete Block Building at 10 m Ground Range
(Megarad)

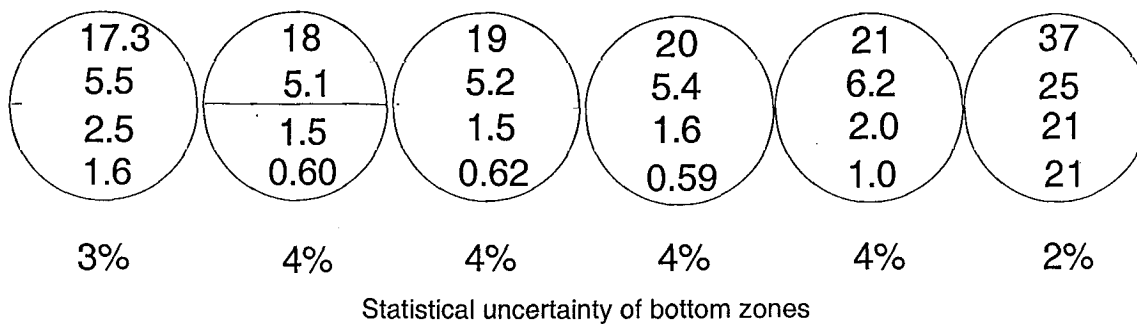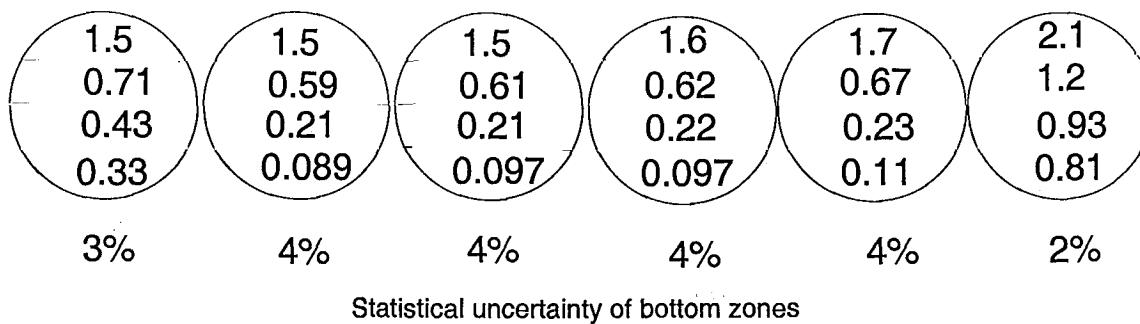Yield: 10 kT   HOB: 10m

14 Mev neutrons

1000	1200	1400	1600	2100
150	150	180	220	810

170	23	25	31	63	2400
90	11	10	13	51	1100
58	5.1	4.4	5.6	26	620
42	2.9	2.2	3.0	15	400

2%   5%   5%   5%   3%   1%

Statistical uncertainty of bottom zones

Fig. A79

Fission neutrons
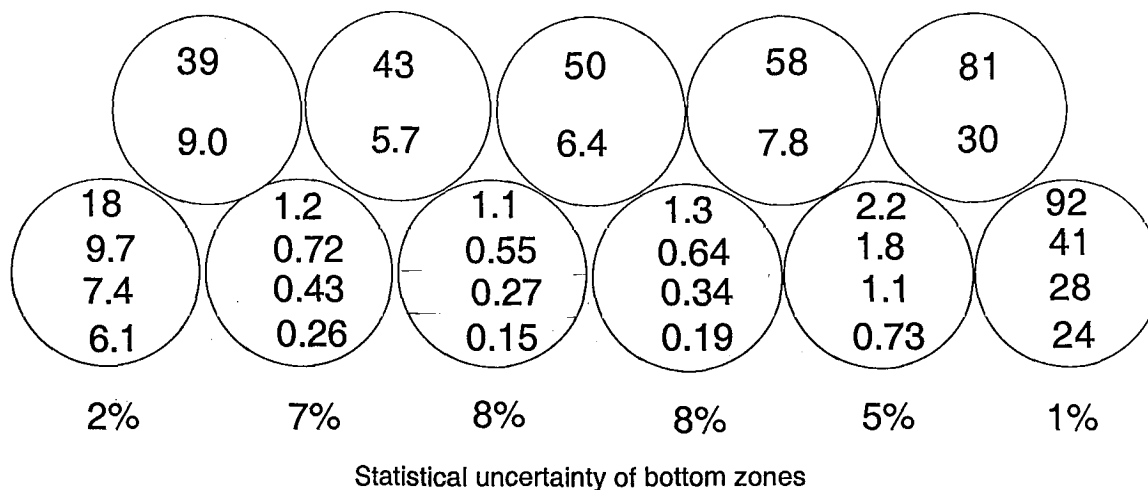
39	43	50	58	81
9.0	5.7	6.4	7.8	30

18	1.2	1.1	1.3	2.2	92
9.7	0.72	0.55	0.64	1.8	41
7.4	0.43	0.27	0.34	1.1	28
6.1	0.26	0.15	0.19	0.73	24

2%   7%   8%   8%   5%   1%

Statistical uncertainty of bottom zones

Fig. A80

Radiation Dose in One-Ton Containers inside a Concrete Block Building at 20m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

210	260	290	320	560
29	24	27	33	31

48	4.1	4.3	5.1	21	740
25	2.1	1.9	2.4	20	440
16	1.1	0.90	1.3	8.7	330
12	0.69	0.47	0.74	6.4	280

2%	6%	6%	6%	3%	0.6%

Statistical uncertainty of bottom zones

Fig. A81

Fission neutrons
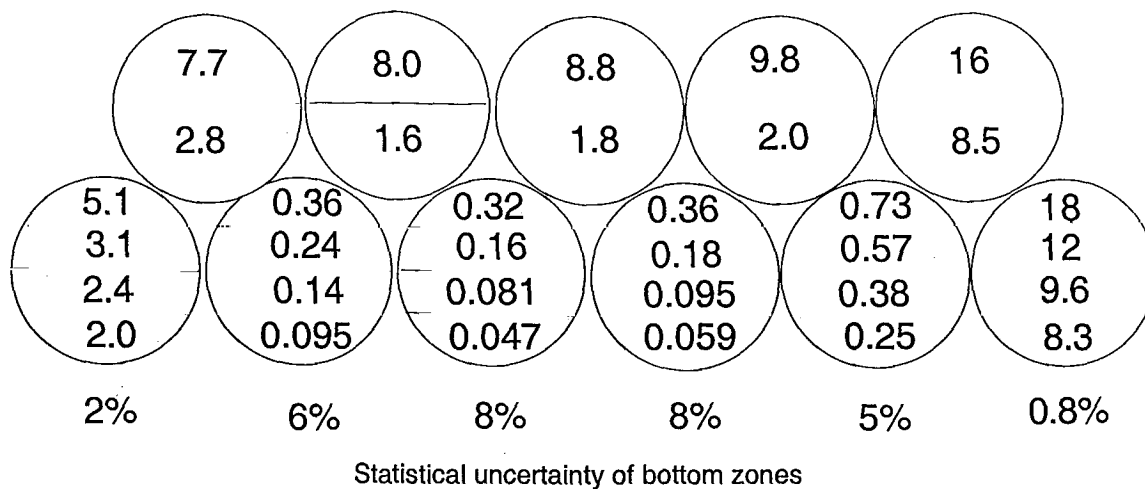
7.7	8.0	8.8	9.8	16
2.8	1.6	1.8	2.0	8.5

5.1	0.36	0.32	0.36	0.73	18
3.1	0.24	0.16	0.18	0.57	12
2.4	0.14	0.081	0.095	0.38	9.6
2.0	0.095	0.047	0.059	0.25	8.3

2%	6%	8%	8%	5%	0.8%

Statistical uncertainty of bottom zones

Fig. A82

Radiation Dose in One-Ton Containers inside a Concrete Block Building at 40 m Ground Range
(Megarad)

Yield: 10 kT   HOB: 10m

14 Mev neutrons

44	46	50	55	140	
7.0	4.6	4.8	5.9	90	
14	0.94	0.87	0.96	4.9	170
7.4	0.50	0.39	0.49	4.0	110
4.9	0.29	0.21	0.27	2.2	94
3.6	0.18	0.13	0.18	1.9	90
2%	8%	9%	8%	4%	0.8%
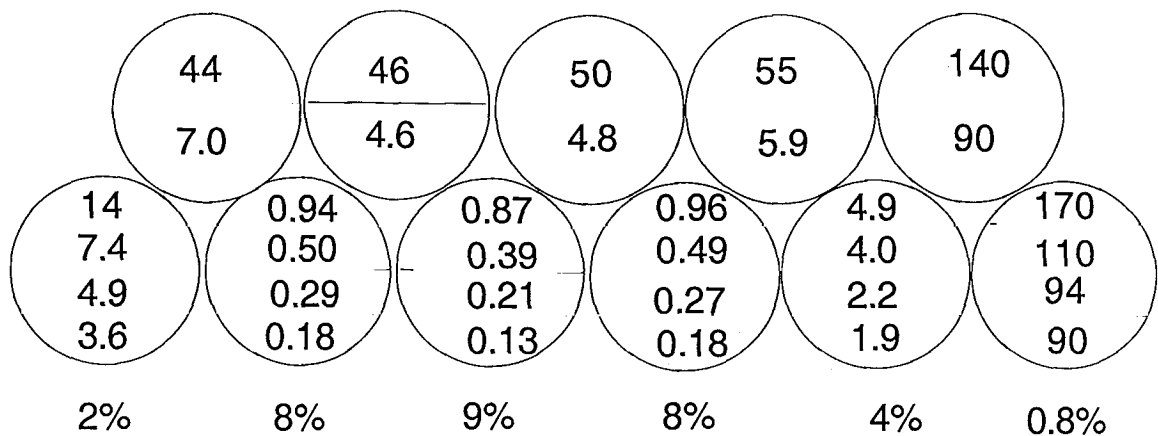
Statistical uncertainty of bottom zones

Fig. A83

Fission neutrons

3.1	3.1	3.2	3.5	6.0	
1.0	0.51	0.51	0.59	3.2	
2.1	0.12	0.096	0.12	0.20	7.2
1.2	0.077	0.051	0.059	0.16	4.3
0.89	0.047	0.028	0.035	0.11	3.5
0.72	0.028	0.018	0.019	0.069	3.2
2%	9%	10%	10%	6%	1%
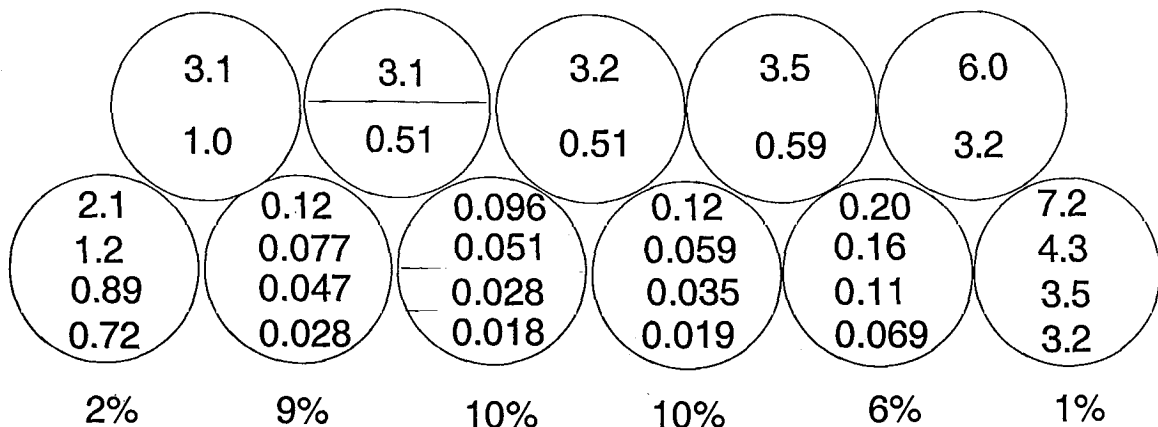
Statistical uncertainty of bottom zones

Fig. A84

Radiation Dose in One-Ton Containers inside a Concrete Block Building at 80 m Ground Range
(Megarad)

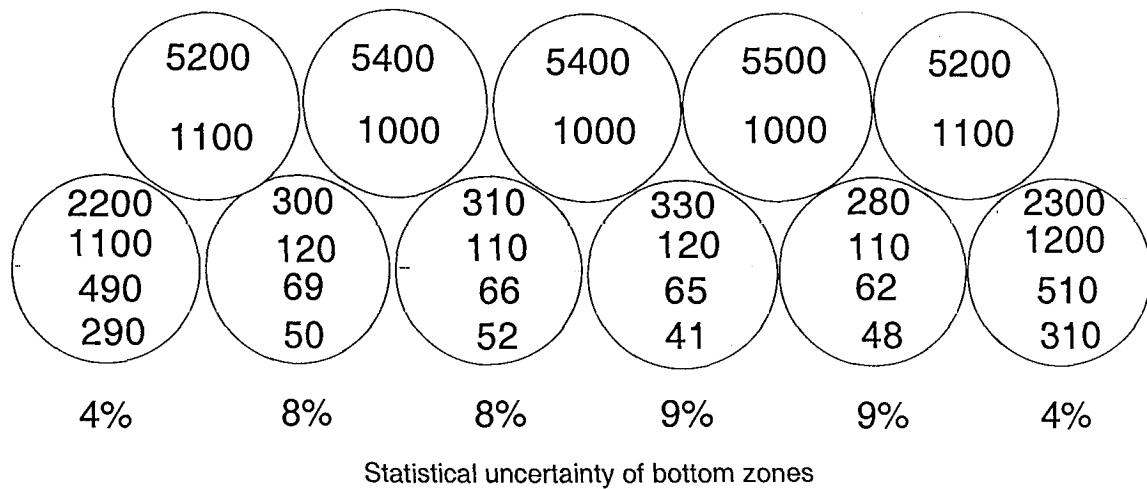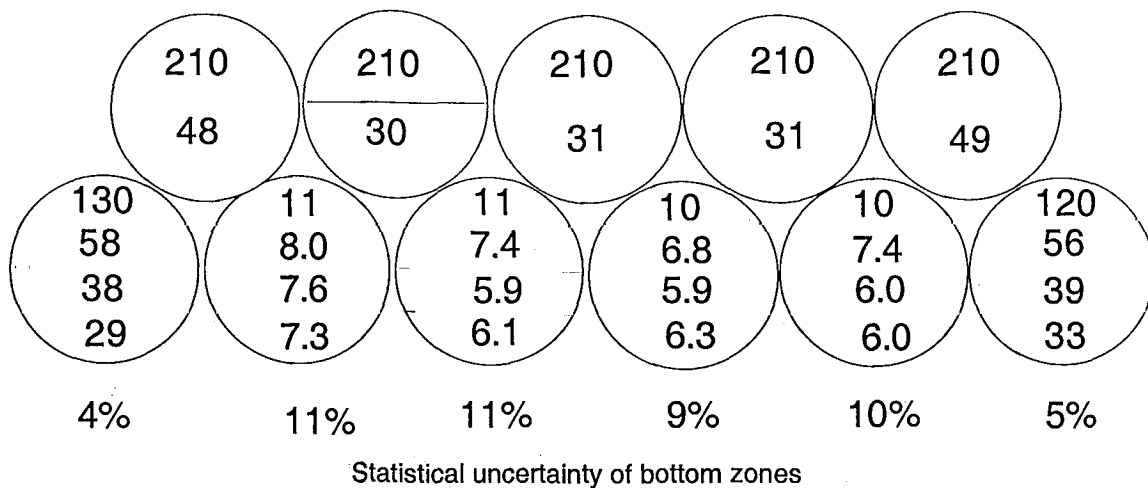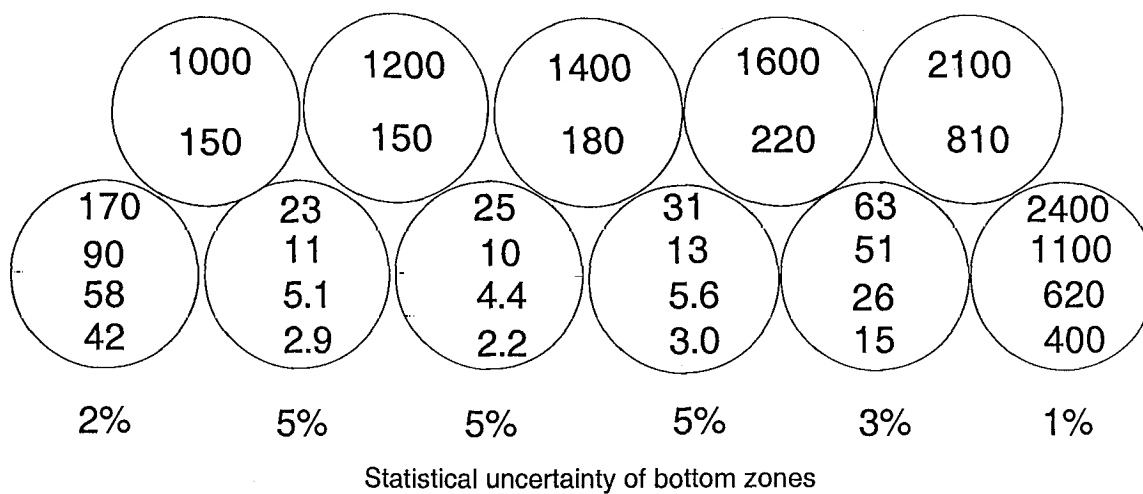Yield: 10 kT   HOB: 10m

14 Mev neutrons

9.3	9.2	10	11	29
1.9	1.1	1.2	1.3	20

4.1	0.25	0.22	0.22	0.98	36
2.2	0.14	0.14	0.11	0.75	24
1.5	0.085	0.046	0.063	0.48	21
1.1	0.052	0.027	0.042	0.44	20

3%   11%   15%   13%   5%   1%

Statistical uncertainty of bottom zones

Fig. A85

Fission neutrons

0.94	0.89	0.93	0.97	1.5
0.32	0.16	0.16	0.17	0.79

0.70	0.038	0.033	0.036	0.058	1.7
0.39	0.027	0.017	0.018	0.044	1.0
0.30	0.016	0.0084	0.0097	0.028	0.85
0.25	0.011	0.0050	0.0050	0.022	0.76

2%   11%   13%   12%   8%   1%

Statistical uncertainty of bottom zones

Fig. A86

Radiation Dose in 200-liter Drums inside a Metal Roof Building with R=10 meters (Megarad)

Yield: 10kT   HOB: 10 m

14 Mev neutrons

In drums — Next to drums — Under burst point

In drums						Next to drums	Under burst point
2900 / 730	3100 / 770	3300 / 850	3500 / 950	3400 / 850	3500 / 890		7800 / 2900
390 / 230 / 150 / 120	260 / 140 / 72 / 42	290 / 150 / 74 / 42	320 / 160 / 81 / 44	320 / 160 / 81 / 46	340 / 180 / 88 / 50	360 / 180 / 93 / 52	1200 / 630 / 330 / 180
2%	3%	3%	3%	3%	3%	2%	2%

Statistical uncertainty of bottom zones

Fig. A87

Fission neutrons

In drums — Next to drums — Under burst point

In drums						Next to drums	Under burst point
110 / 23	110 / 17	120 / 18	130 / 20	120 / 18	130 / 19		320 / 56
30 / 19 / 14 / 12	7.2 / 4.5 / 2.8 / 2.0	7.1 / 4.1 / 2.4 / 1.5	7.4 / 4.4 / 2.6 / 1.6	7.9 / 4.4 / 2.6 / 1.5	7.3 / 4.7 / 2.7 / 1.6	8.5 / 4.8 / 2.9 / 1.8	23 / 13 / 7.2 / 4.3
2%	4%	4%	4%	4%	4%	3%	3%

Statistical uncertainty of bottom zones

Fig. A88

Radiation Dose in 200-liter Drums inside a Metal Roof Building with R= 20 meter (Megarad)

Yield: 10kT   HOB: 10 m

14 Mev neutrons

In drums					Next to drums	Under burst point

750	790	830	870	780	800	7800
130	110	120	120	110	120	2900
110	41	43	44	42	42	47	1200
66	24	23	23	23	23	24	630
49	14	13	12	12	13	13	330
41	9.4	7.6	7.3	7.2	7.7	7.4	180
2%	4%	4%	4%	4%	4%	3%	2%

Statistical uncertainty of bottom zones

Fig. A89

Fission neutrons

In drums					Next to drums	Under burst point

30	30	31	33	27	29	320
7.3	4.2	4.3	4.5	4.0	4.1	55
12	2.2	1.8	1.9	1.9	1.7	1.9	23
7.0	1.4	1.1	1.1	1.1	1.1	1.1	12
5.6	0.94	0.66	0.68	0.63	0.63	0.65	7.1
4.8	0.67	0.44	0.43	0.39	0.42	0.40	4.4
2%	5%	5%	5%	5%	5%	5%	3%

Statistical uncertainty of bottom zones
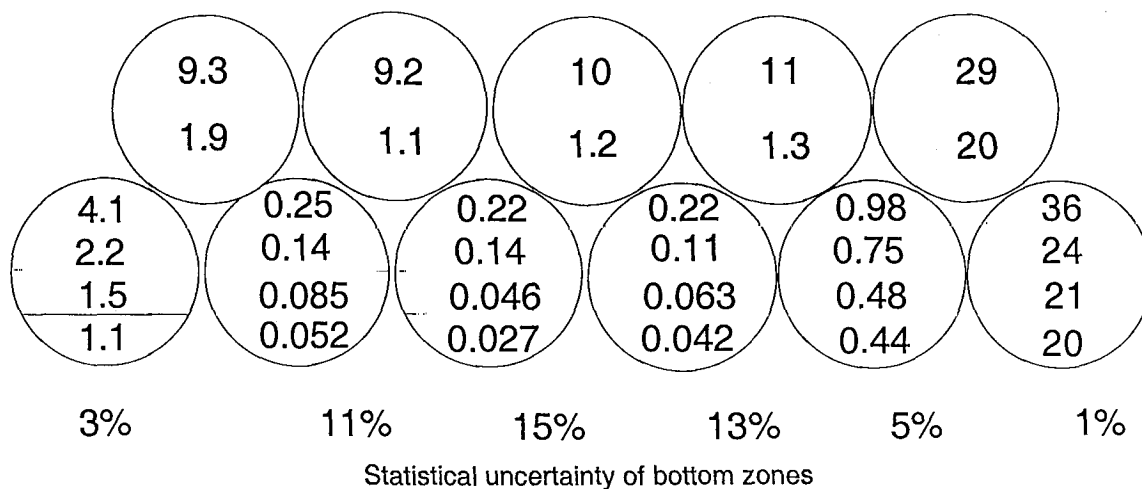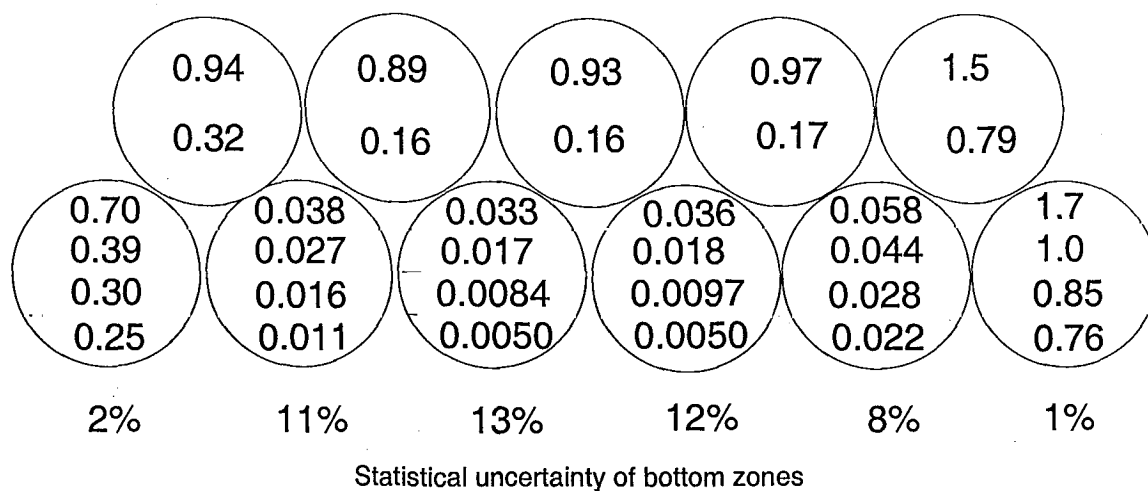
Fig. A90

Radiation Dose in 200-liter Drums inside a Metal Roof Building with R=40 meter (Megarad)
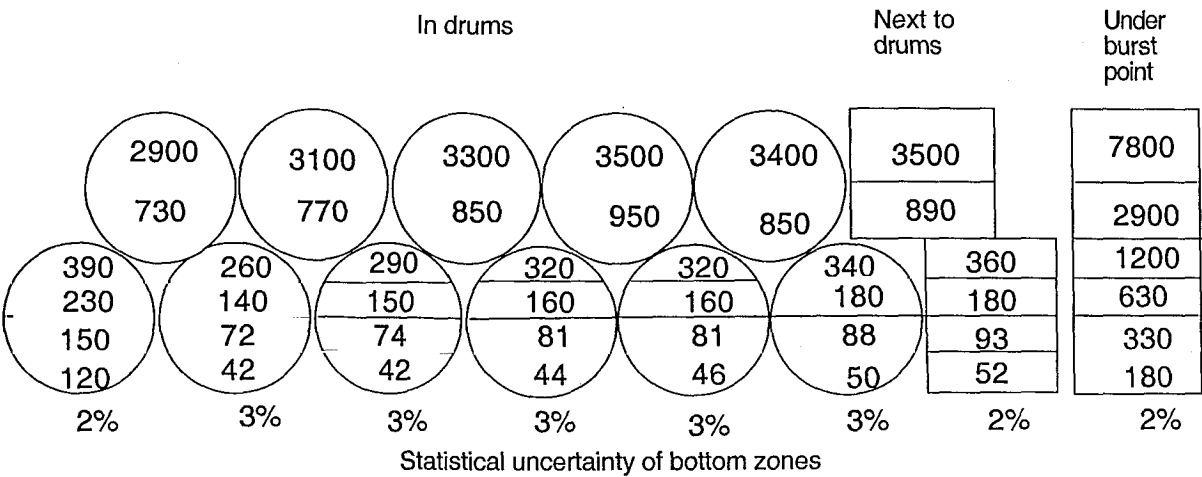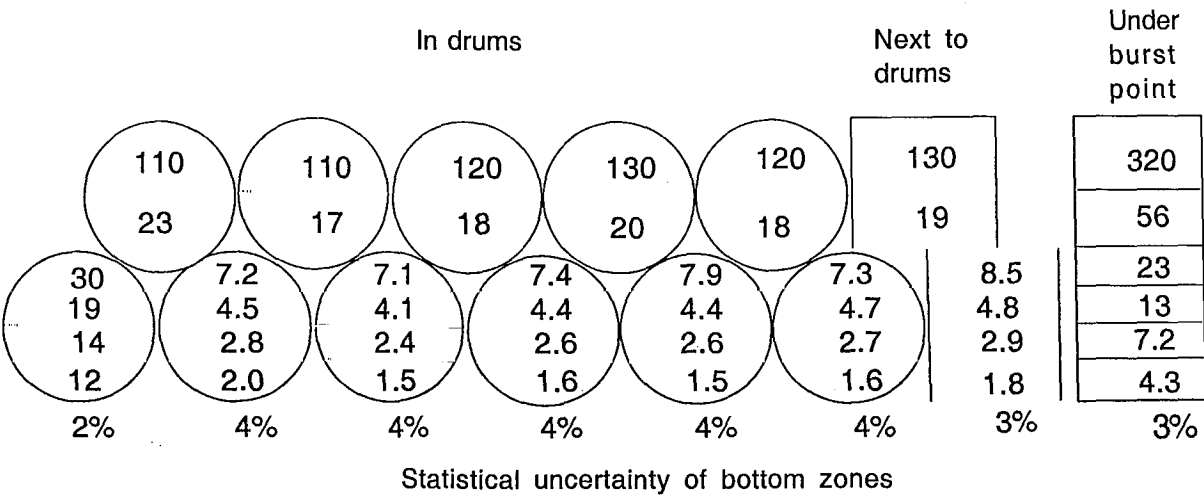
Yield: 10kT   HOB: 10 m

14 Mev neutrons

In drums   Next to drums   Under burst point

130	130	130	130	110	120		7800
23	16	16	16	14	150		2900
							1200
30	7.4	6.4	6.8	6.4	6.1	62	630
18	4.6	3.8	3.6	3.6	3.5	34	330
13	2.8	2.3	2.1	2.1	2.0	20	180
12	2.1	1.4	1.3	1.3	1.3	12	
2%	3%	4%	4%	4%	4%	3%	1%

Statistical uncertainty of bottom zones

Fig. A91

Fission neutrons

In drums   Next to drums   Under burst point

6.7	6.3	6.5	6.6	5.5	5.7		320
2.1	1.1	1.1	1.1	0.99	0.95		55
						0.43	23
3.8	0.62	0.50	0.48	0.50	0.44	0.26	12
2.3	0.43	0.31	0.29	0.29	0.28	0.16	7.2
1.7	0.29	0.19	0.17	0.18	0.18	0.10	4.4
1.6	0.21	0.12	0.12	0.11	0.11		3%
2%	5%	6%	6%	6%	6%	6%	

Statistical uncertainty of bottom zones
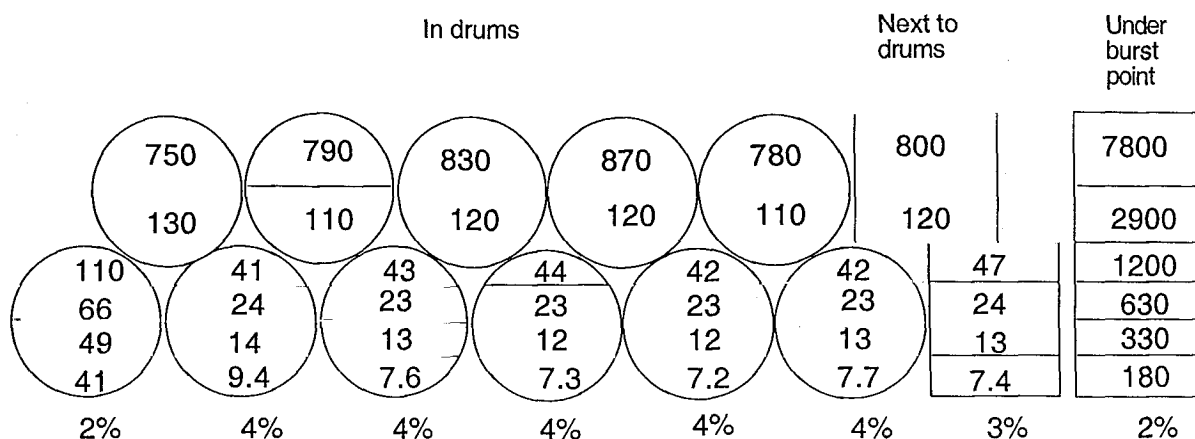
Fig. A92

Radiation Dose in 200-liter Drums inside a Metal Roof Building with R=80 meter (Megarad)
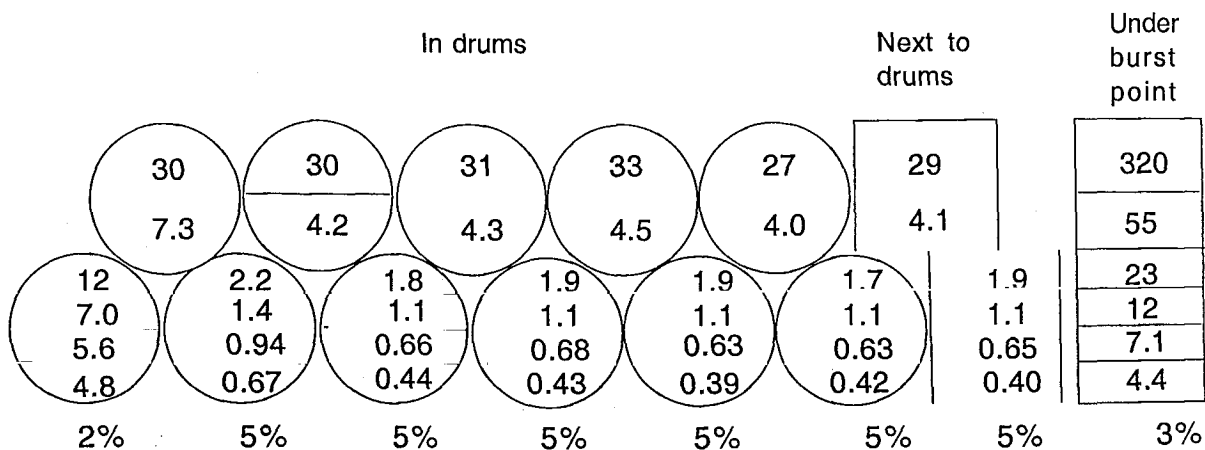
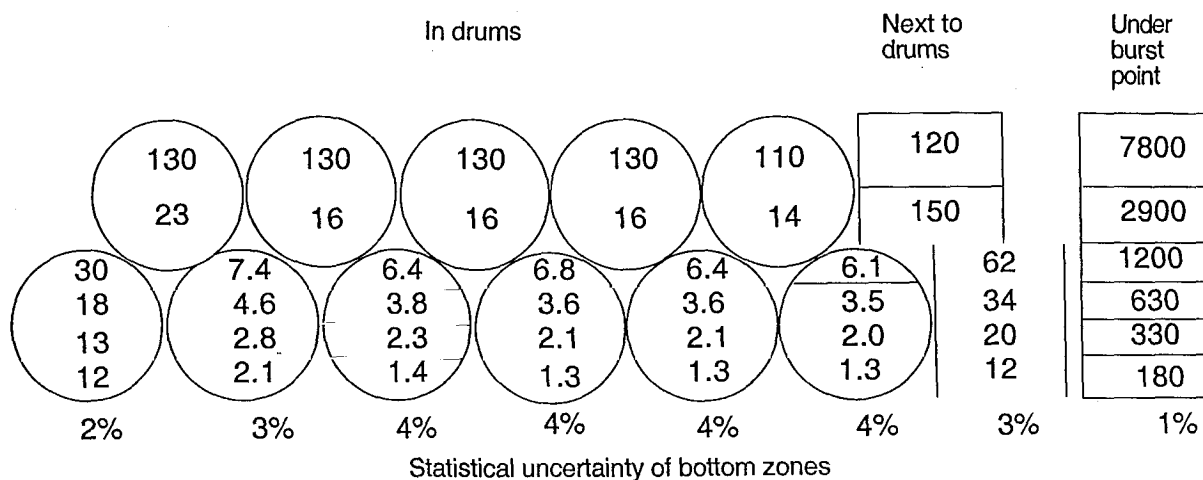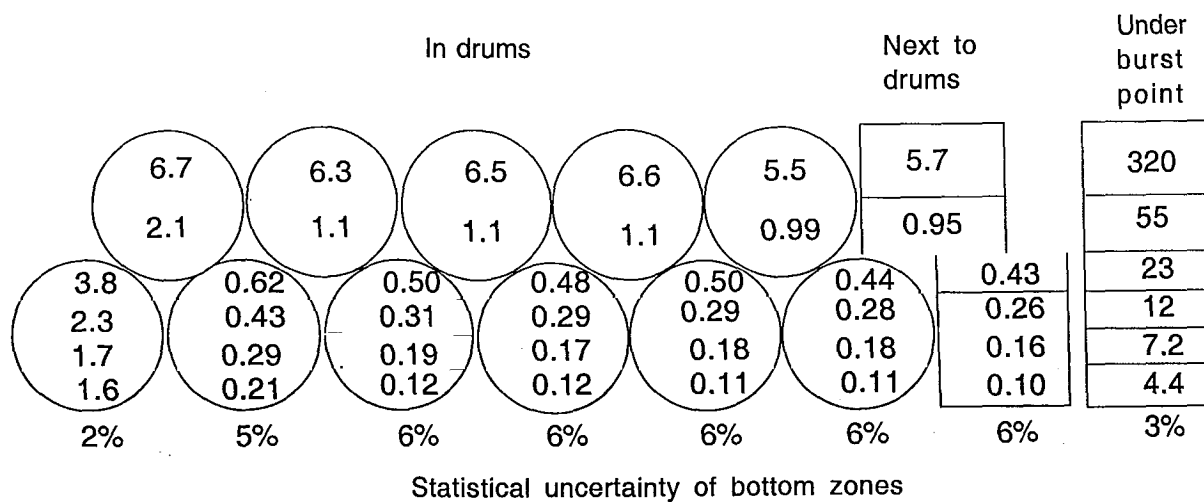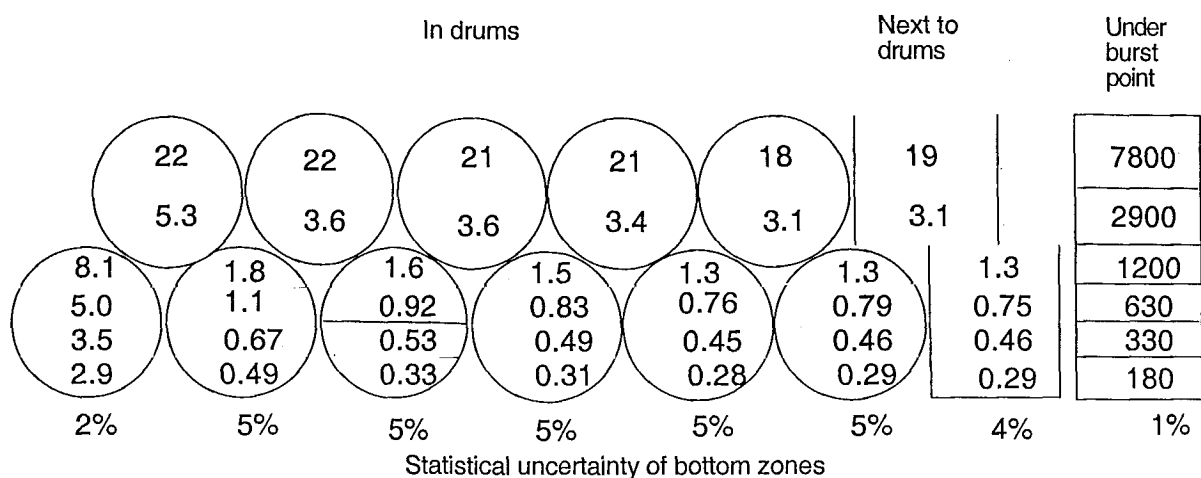## Yield: 10kT   HOB: 10 m

14 Mev neutrons

| In drums | | | | | Next to drums | | Under burst point |

Fig. A93

Fission neutrons

| In drums | | | | | Next to drums | | Under burst point |

Statistical uncertainty of bottom zones

Fig. A94

Radiation Dose in 200-liter Drums inside a Metal Roof Building with R=20 meter (Megarad)

Yield: 10kT   Neutron spectrum: 14 Mev

5 m HOB

	In drums					Next to drums	Under burst point
420	430	470	490	410	450		34000
63	47	48	49	46	51		12000
79	22	20	20	19	19	22	4900
50	14	11	11	11	12	12	2500
37	8.3	6.8	6.5	6.5	6.6	6.8	1300
32	6.1	4.4	4.0	4.2	4.1	4.3	680
2%	4%	5%	4%	4%	4%	4%	1%

Statistical uncertainty of bottom zones

Fig. A95

20 m HOB

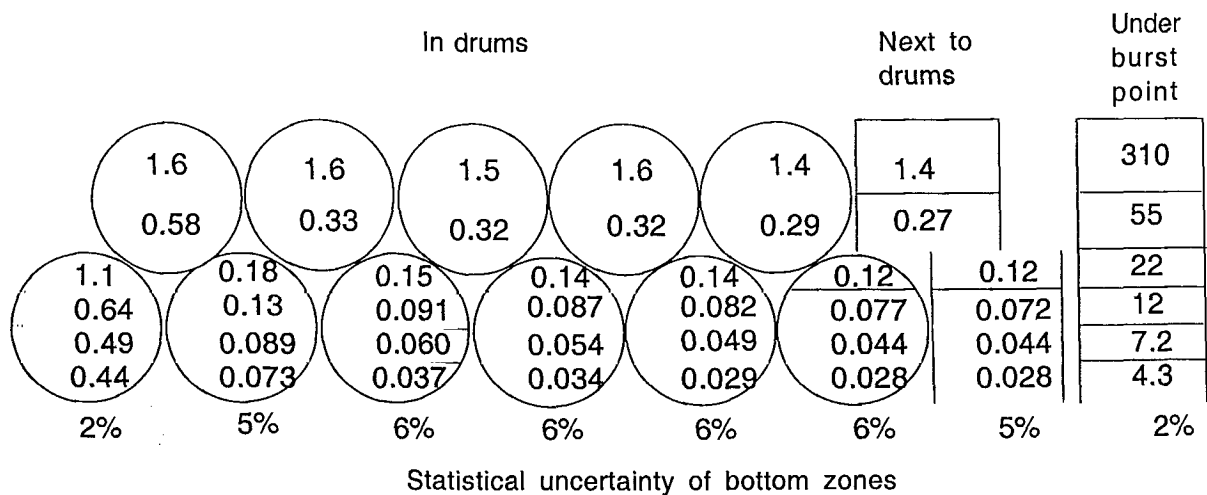|	In drums					Next to drums	Under burst point
740	770	790	820	770	740		1800
200	200	210	220	190	190		680
120	73	74	77	73	74	74	290
73	38	38	39	37	39	37	150
50	20	19	19	19	20	20	81
38	12	11	11	11	11	11	44
1%	2%	2%	2%	2%	2%	2%	2%

Statistical uncertainty of bottom zones

Fig. A96

Radiation Dose in 200-liter Drums inside a Metal Roof Building with R=20 meter (Megarad)

Yield: 10kT   Neutron spectrum: 14 Mev

55 m HOB

In drums	Next to drums	Under burst point

Statistical uncertainty of bottom zones

Fig. A97

138 m HOB

In drums	Next to drums	Under burst point

Statistical uncertainty of bottom zones

Fig. A98

Radiation Dose in 200-liter Drums inside a Metal Roof Building with R=20 meter (Megarad)

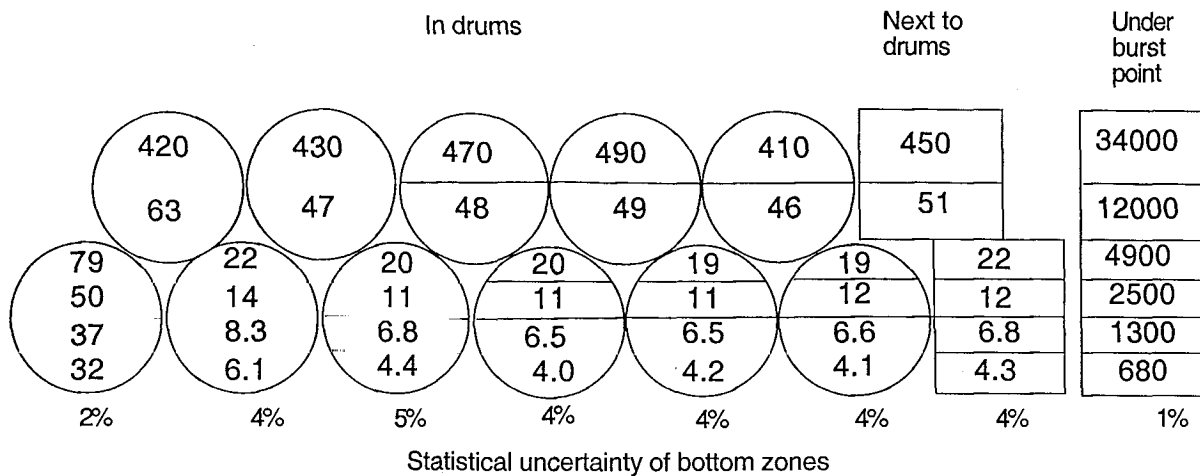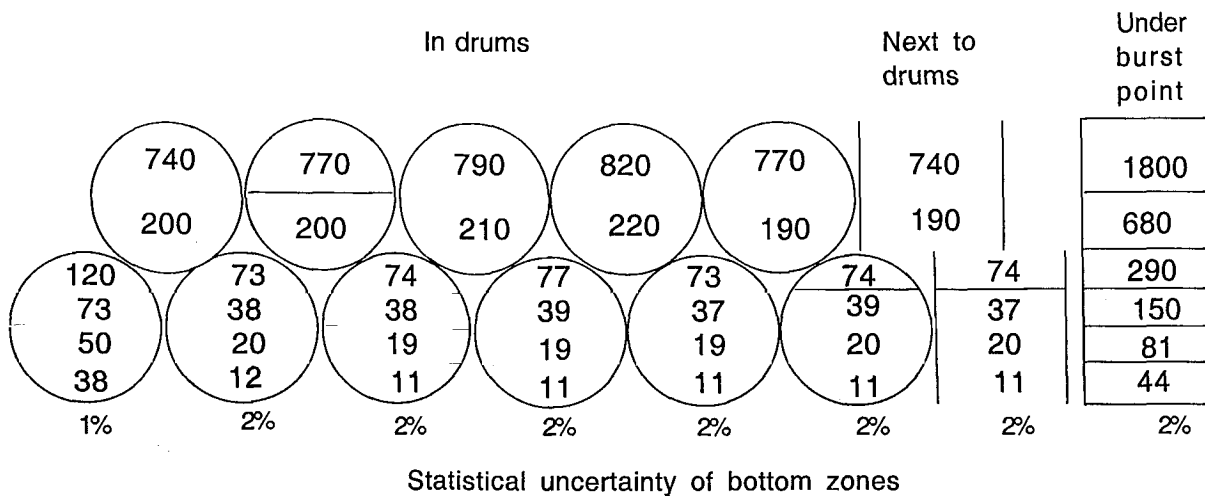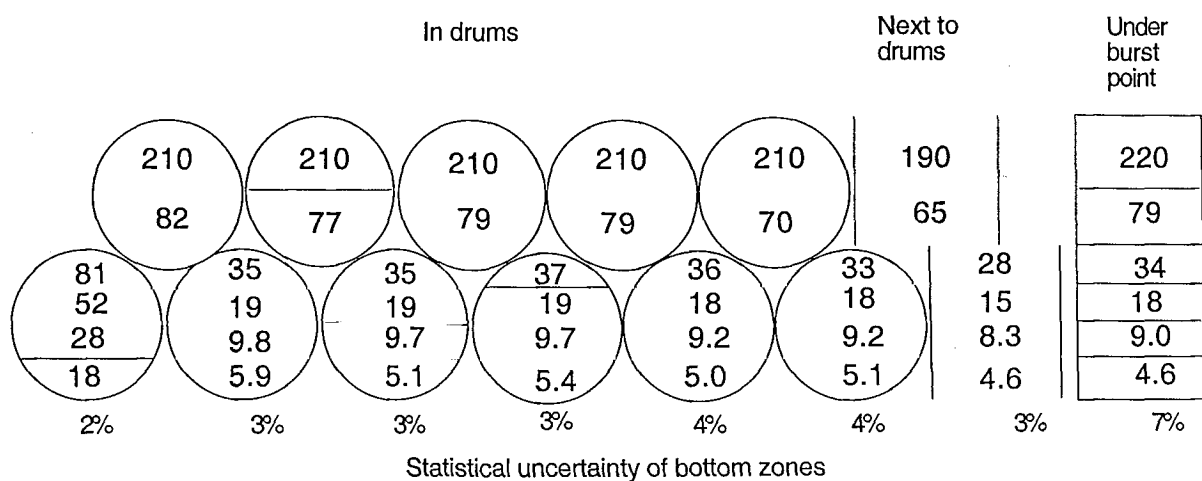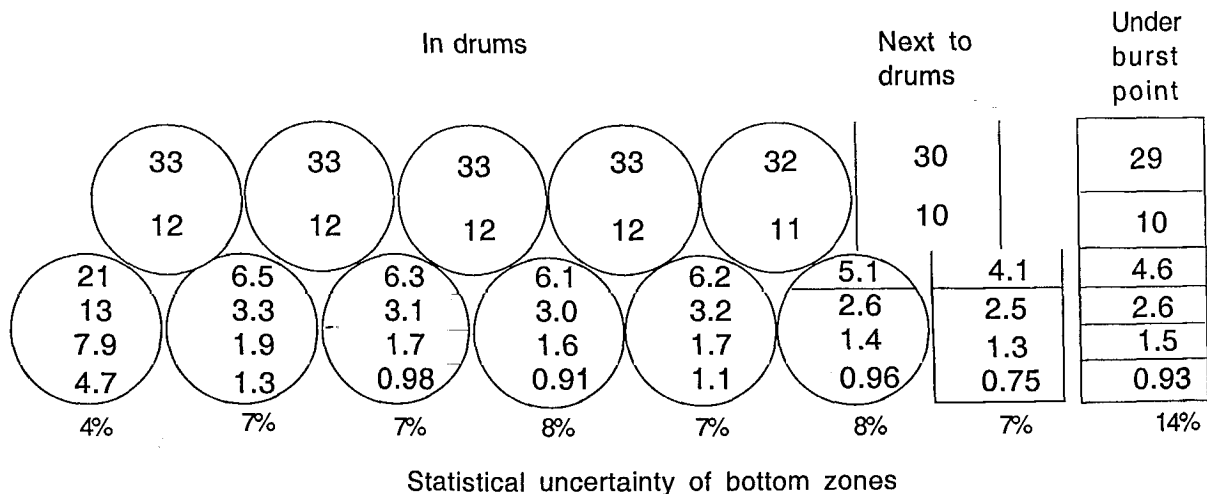Yield: 10kT   Neutron spectrum: Fission

5 m HOB

In drums   Next to drums   Under burst point

In drums					Next to drums	Under burst point
20	20	21	21	17	19	1300
5.7	3.2	3.1	3.1	2.9	2.9	230
10 6.1 4.8 4.3	1.8 1.2 0.81 0.62	1.4 0.86 0.52 0.35	1.4 0.82 0.51 0.31	1.3 0.77 0.47 0.32	1.3 0.81 0.47 0.29	
					1.3 0.77 0.46 0.28	91 50 29 17
2%	4%	5%	4%	4%	4%	4% 1%

Statistical uncertainty of bottom zones

Fig. A99

20 m HOB

In drums   Next to drums   Under burst point

In drums					Next to drums	Under burst point
30	30	31	32	28	29	76
7.3	4.9	4.8	5.1	4.3	4.4	14
10 6.2 4.9 4.1	2.2 1.5 0.89 0.61	2.0 1.1 0.65 0.42	2.0 1.2 0.69 0.42	2.0 1.2 0.66 0.40	1.8 1.1 0.67 0.42	
					1.9 1.1 0.69 0.42	5.6 3.3 1.8 1.1
2%	5%	5%	5%	5%	5%	4% 6%

Statistical uncertainty of bottom zones

Fig. A100

Radiation Dose in 200-liter Drums inside a Metal Roof Building with R=20 meter (Megarad)
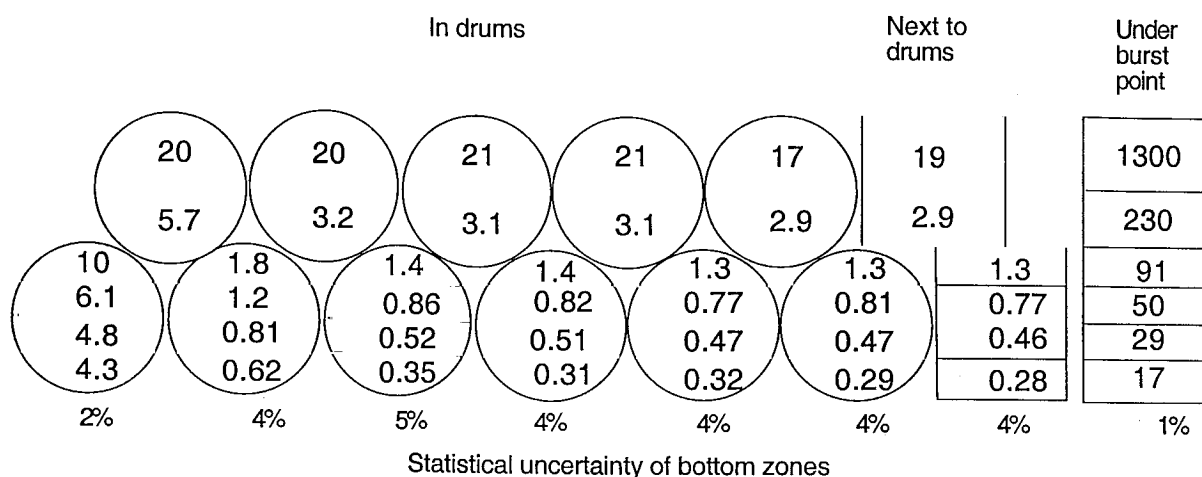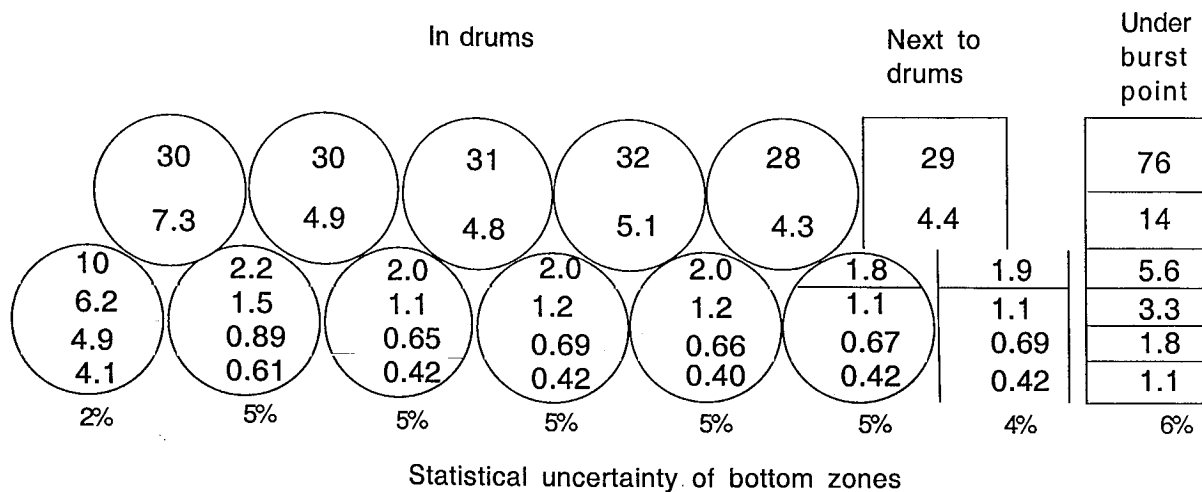
Yield: 10kT   Neutron spectrum: Fission

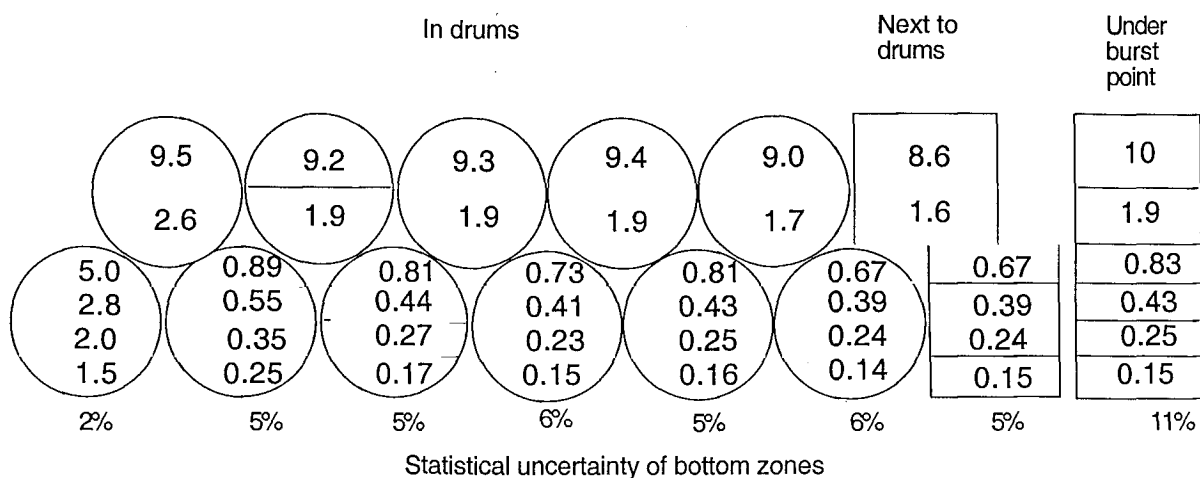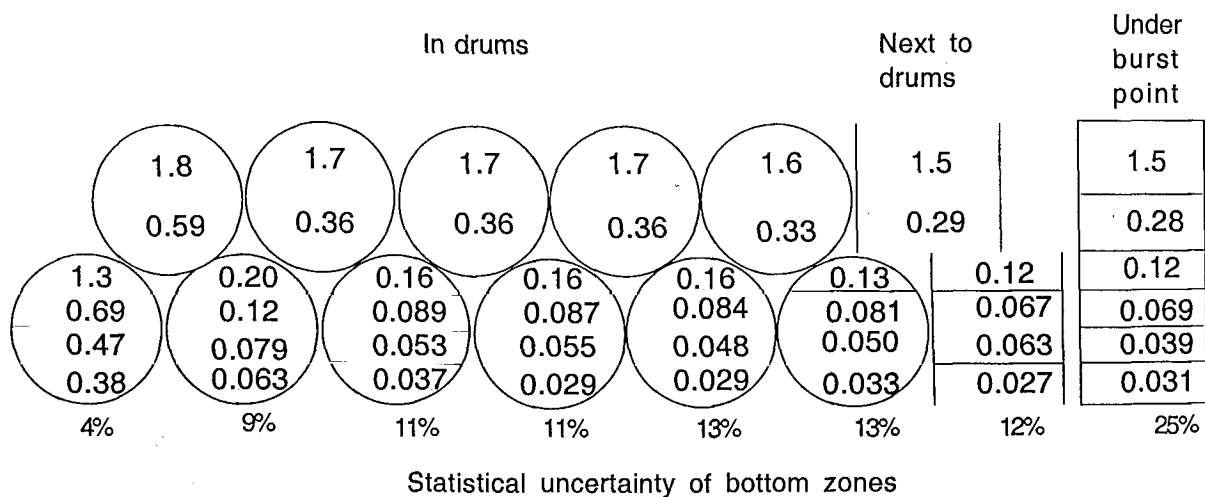### 55 m HOB

In drums   Next to drums   Under burst point

| 9.5 | 9.2 | 9.3 | 9.4 | 9.0 | 8.6 | 10 |
| 2.6 | 1.9 | 1.9 | 1.9 | 1.7 | 1.6 | 1.9 |

5.0	0.89	0.81	0.73	0.81	0.67	0.67	0.83
2.8	0.55	0.44	0.41	0.43	0.39	0.39	0.43
2.0	0.35	0.27	0.23	0.25	0.24	0.24	0.25
1.5	0.25	0.17	0.15	0.16	0.14	0.15	0.15

| 2% | 5% | 5% | 6% | 5% | 6% | 5% | 11% |

Statistical uncertainty of bottom zones

Fig. A101

138 m HOB

In drums   Next to drums   Under burst point

| 1.8 | 1.7 | 1.7 | 1.7 | 1.6 | 1.5 | 1.5 |
| 0.59 | 0.36 | 0.36 | 0.36 | 0.33 | 0.29 | 0.28 |

1.3	0.20	0.16	0.16	0.16	0.13	0.12	0.12
0.69	0.12	0.089	0.087	0.084	0.081	0.067	0.069
0.47	0.079	0.053	0.055	0.048	0.050	0.063	0.039
0.38	0.063	0.037	0.029	0.029	0.033	0.027	0.031

| 4% | 9% | 11% | 11% | 13% | 13% | 12% | 25% |

Statistical uncertainty of bottom zones

Fig. A102